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EDITED BY

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CONTENTS:

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ALFRED N. GOLDSMITH, Ph. D.

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A DISCUSSION ON EXPERIMENTAL TESTS OF THE RADIATION LAW FOR RADIO OSCILLATORS.*

Opened by Professor Michael I. Pupin, Ph.D., *Professor of Electro-Mechanics, Columbia University.*

I have been requested to speak before your Institute and I replied that, altho I am much interested in radio-telegraphy, and have done some work in that field, yet at the present time my chief interest lies in another direction. However, my work during the last three or four years has suggested a method which might prove useful in determining the law of radiation from antennae.

I number among my friends many workers in the radio field, among them such men as Professor Braun, Marconi, Hewitt, de Forest, Fessenden and Max Wien; the last being a colleague of mine, a fellow-student, and one with whom I have corresponded in regard to the matter of the determination of the radiation law. It struck me that there was one thing which perhaps these men have not done as thoroly as it might be done, and that is the determination of the relation between the frequency of the alternating current in the radiator and the capacity of the radiator to throw off energy. Of course you all know that the higher the frequency, other things being equal, the faster the energy is radiated. But what is the exact law, and what its theoretical foundation? I have always been interested in that. I have, for instance, asked Mr. Fessenden whether forty thousand cycles is sufficiently high for efficient radiation, and he replied that even lower frequencies might be employed. Marconi at that time said that he preferred a half million cycles per second, and thus we encountered a difference of opinion.

The extremely high frequency of these currents viewed from the standpoint of ordinary electrical engineering technique makes it difficult to produce trustworthy generators, and the higher the

* Lecture delivered before The Wireless Institute, one of the component societies which combined to form the Institute of Radio Engineers.

frequency, the more difficult it becomes to produce a high power generator of continuous oscillations. Of course, if we are satisfied with currents which die away as rapidly as the sound from the crack of a whip, there is no difficulty in producing machinery of that kind. But if we wish to produce sustained electrical oscillations the problem becomes much more difficult. I regard the one hundred thousand cycle alternators which the General Electric Company produced for Mr. Fessenden, to deliver two kilowatts, as a triumph of mechanical knowledge and engineering skill. If frequencies higher than this are required, it becomes almost impossible to produce the machine, if a considerable output is required.*

If frequencies of between twenty and forty thousand cycles could be used, the conditions would be much more favorable, as it is quite within reach to make alternators of considerable output, say ten kilowatts, or more, for these frequencies. If radiotelegraphy is ever to become an important branch of electrical engineering, its advance will be brought about when we have very powerful generators capable of producing continuous radiation, and the simplest way of obtaining such a generator is by means of the high power alternator. Even at the present time the most nearly ideal way of producing such undamped radiation is by the use of the high frequency alternator.

As I have said, if we could get along with forty thousand cycles a second it would not be difficult to build an alternator of the requisite power. But how can we tell if forty thousand cycles would be satisfactory? We can tell only when we know the law of radiation, the relation between the frequency and the energy radiated at that frequency. At the present time this cannot be said to have been completely done.

There are two ways of arriving at the law of radiation. There is a purely mathematical way. Thus we may consider the case of a high vertical wire connected to the ground, which we may take to be a good conductor. It may also for purposes of approximate calculation be assumed to be an infinite plane. We know how the rate of radiation in this case varies with the frequency, but even this simple case has not been completely solved.

When we come to the complicated forms of antennae which we use in practice to-day, it becomes excessively difficult to work out the theory mathematically. But even if we could work it

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* See Editorial Notes at the end of this Discussion.

out completely mathematically, a simple experimental method would be preferable for many purposes. When Maxwell first worked out the formula for the inductance of a cylindrical coil, he produced an elaborately beautiful formula for calculating the inductance in terms of the length of the coil, the size of the wire, and various other quantities. But at the end of his calculations he says that even in this simple case the experimental method would determine the desired quantity much more satisfactorily than the mathematical method. In the case of the antennae employed in radio-telegraphy this is even more so. Even if we had the formula for the energy radiated from the antenna at various frequencies, it would be so complicated that it would be better to determine the desired relations experimentally after all. Various investigators have attempted to obtain the law experimentally with more or less success, but the work has not yet been brought to a definite close. My remarks this evening concern a method which I have used in other fields not directly related to radio-communication, and in these it has worked very well. I see no reason why it should not work equally well in determining the radiation factor. I have not seen this method mentioned, and while it may be known to those working in the art no harm will be done by repeating a description of it.

We start from very simple premises. We consider a conductor or part of a system of electrical conductors between the points R and S. If we impress an electro-motive force between these two points, we throw energy into the system by this means. We assume that the E. M. F. is of the sinusoidal alternating type and therefore of the form

$$e = E \cos pt.$$

That is, it is a simple harmonic E. M. F. and it will give rise to a simple harmonic current of definite amplitude and phase. Calling this current i we have

$$i = I \cos (pt - u).$$

The energy, or rather the rate at which energy is being thrown into the system is, of course, e i. If we wish to know the energy poured into the system in a unit of time, the mean value of e i is taken, according to the well known rule; that is, it is the mean value of the product of the instantaneous values of current and E. M. F. The E. M. F. does work on the system by overcoming certain reactions between the points R and S.

In every case of this kind there are two reactions, and this is

Figure 1

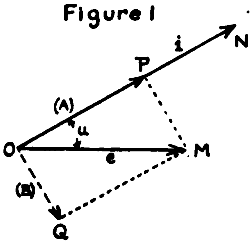


Figure 4

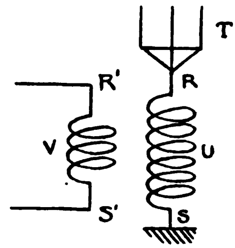


Figure 2

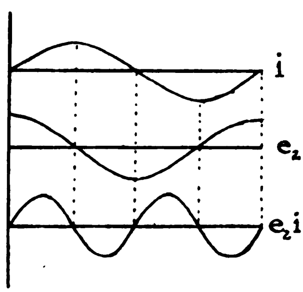


Figure 5

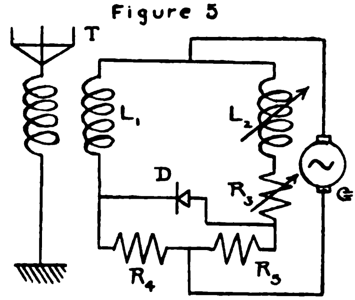


Figure 3

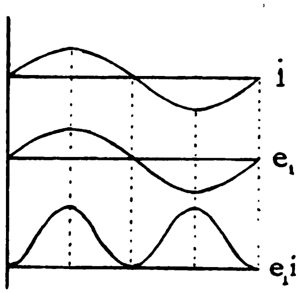
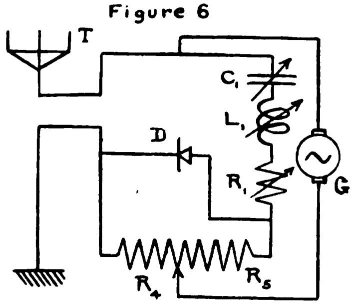


Figure 6



so without exception. For want of better names, we call these two classes the conservative and the non-conservative classes or reactions, respectively. There is, of course, an excellent reason for dividing the reactions into these two classes, as will be shortly seen.

Let us consider the difference between these two classes of reactions more closely. Every E. M. F. can be divided into two components in an infinite number of ways. We will divide the E. M. F. between A and B into components, as follows:

$$E \cos pt = A \cos(pt - u) - B \sin(pt - u).$$

These components are at right angles to each other. One of these components is exactly in phase with the current and the other is at right angles to the current. This resolution is shown graphically in Figure 1. Let OM represent the E. M. F. and ON the resulting current. The angle of phase displacement between these is angle NOM. Then OP is the component of the E. M. F. in phase with the current, and OQ the component at right angles to it. The lengths of OP and OQ are the A and B of the above equation.

It is perfectly well known that it does not make any difference how many reactions of an electrical kind there are between the two points; they could all be summed up in two components. The system may have any number of parts, but if the reactions are simple harmonic, they may be summed up into two.

By what may be termed an extension of Newton's third Law of Motion, the sum of the impressed forces and of the reactions of the system is always zero. So that altho the instantaneous value of the work done by the E. M. F. e_2 is not zero, its mean value is zero. Representing the mean value of the work done by M(ei), we have

$$M(ei) = O.$$

For if we write equation (1) above in the form,

$$e = e_1 + e_2, \text{ we obtain}$$

$$M(ei) = M(e_1 i) + M(e_2 i).$$

Let us consider the reaction $e_2 = B \sin(pt - u)$. It is what may be called the conservative reaction. During one-half of the cycle it does work which is positive, and during one-half it does work which is negative, and the sum is zero.

What is the meaning of positive and negative work? Speaking in an elementary way, if positive work means that energy is being supplied to the system between the two points, negative work means that the system is giving off energy between these points. So that negative work is done when the system does work against the E. M. F., and it does this by giving up its stored energy. The energy is stored in either an electrical or a magnetic field. During one-half the cycle the impressed forces do work which is stored up in the fields, and during the other half the energy in returning helps the generator to produce an E. M. F. This is the reason e_2 is called the conservative reaction. The energy it supplies is stored in the fields and can be gotten back. The other reaction does work which has a mean value greater than zero, and cannot be gotten back. Hence e_1 may be called the non-conservative reaction.

In Figures 2 and 3 are shown the E. M. Forces, e_2 and e_1, the current i; and the corresponding rates at which energy is being delivered at each instant, that is e_2i and e_1i. It will be seen that in Figure 2, the total work done upon the system is zero, whereas in the case shown in Figure 3, the total work done upon the system is positive. This work never comes back at all. Where is it? One cannot tell without more careful scrutiny of the physical system considered. We must then differentiate between work which returns and that which does not.

As a special case, (and the one of primary interest to us), let us consider that shown in Figure 4. Here T is the antenna or radiating system, U the secondary of an inductive coupler of which V is the primary. Thus there is impressed between the points R and S an E. M. F. The non-conservative E. M. F. will produce work of a kind that is dissipated. This will include heat generated in the coil U, heat generated in the conductors of the antenna T, heat generated at the ground connection and in the ground, and energy which has been radiated to unknown points. All of the energy which disappears as heat in the conductors or elsewhere, or which is radiated will manifest itself by a non-conservative reaction between the points R and S (or R′ and S′). So that if we had a method of measuring that non-conservative reaction, we should be able to measure the rate at which energy is being radiated after making proper allowance for the energy lost as heat. Fortunately we have a very simple method of doing this.

We shall examine somewhat more closely the reactions and

the currents. In the first place it is clearly evident that the amplitude, I, of the current i is proportional to the amplitude of the impressed E. M. F. Obviously both are zero or infinity simultaneously. Symbolically expressed,

$$I = k E, \text{ where } k \text{ is a constant.}$$

It can be seen from Figure 1 that both I and e are proportional to E. So that A and B are also proportional I. Thus we get

$$A = R_1 I \quad \text{and} \quad B = R_2 I.$$

We must study R_1 and R_2, the two constants. We shall show that they have all the characteristics of a resistance and a reactance respectively. This gives us a clue to a simple method of measuring them.

Consider the expression M(ei) = W, where W is the total work done on the system per second (Mean Value). It can be shown to be equal to ½ A I.

For M(ei)
$= M[A\ I \cos^2(pt - u)] - M[B\ I \sin(pt - u)\cos(pt - u)]$
$= \frac{1}{2}$ A I, since the mean value of the square of the cosine thruout a period is one-half, and the mean value of the square of the sine times the cosine thruout a period is zero. Thus

$$M(ei) = W = \tfrac{1}{2} A I.$$

Substitute for A, its value given above. Then

$$W = \tfrac{1}{2} R_1 I^2.$$

So that R_1 is the quantity which when multiplied by $\frac{1}{2} I^2$ gives the energy which leaves the system permanently in the form of heat or something else. In ordinary circuits, this is the Joulean resistance. But a resistance due to the dissipation of any other form of energy may be similarly treated.

Another point which can be seen from the questions giving the values of A and B is that the angle of phase displacement is given by

$$\tan u = \frac{B}{A} = \frac{R_1 I}{R_2 I} = \frac{R_1}{R_2}.$$

This gives the tangent of the angle of lag. Since R_1 and R_2 fulfill all these conditions they have all the characteristics of ordinary resistances and reactances. Therefore we can determine them by the *WHEATSTONE BRIDGE.*

Energy is thrown into the antenna thru an electromag-

netic coupling. We wish to know the values of the quantities we have just called the resistance and the reactance. With the high frequencies used in radio-telegraphy there should be no difficulty in determining them within one-tenth of one per cent. It takes some skill, but not very much to handle the bridge. As first used by Wheatstone, it was employed only with direct current, but in 1886 Rayleigh applied it to alternating currents as well. By this latter addition it can be used for the comparison of inductances and capacities as well as resistances.

In Figure 5 is shown one way of determining R_1. The inductances L_2 and the non-inductive resistance R_3 can be varied, as can also the non-inductive resistances R_4 and R_5. G is a generator of alterating current of radio-frequencies. D is some device which makes perceptible the presence of such alternating currents.

From the balance conditions of the bridge, that is, with no current through D, it is easy to calculate the quantity R_1 of the antenna and primary.

We can decompose R_1 into three parts, namely the ohmic resistances in the primary and secondary and the "radiation resistance." If these parts are R_1', R_1'' and R_1''', where R''' is the "radiation resistance" we have

$$\tfrac{1}{2}R_1\, I^2 = \tfrac{1}{2}R_1'\, I^2 + \tfrac{1}{2}R_1''\, I^2 + \tfrac{1}{2}R_1'''\, I^2$$

so that

$$R_1 = R_1' + R_1'' + R_1'''.$$

The last of these quantities is the one desired most. As a matter of fact we keep the quantities R_1' and R_1'' down by using wire of such dimensions that they are negligibly small in comparison with R_1'''.

From the value of R'''_1, it is not difficult to determine the law of radiation, and it is this method which I desired to lay before you.

EDITORIAL NOTES.

Since the above article was written, a 200,000 cycle alternator delivering 1 kilovolt-ampere has been built by the General Electric Company, and the research mentioned above will be carried out with it. Special means for separating true radiation energy from ohmic losses in the antenna, ohmic losses in ground connection,

and from losses due to eddy currents induced in nearby conductors have been devised. And R. Goldschmidt has developed a "reflector type" alternator of comparatively slow speed with which frequencies up to 120,000 cycles per second have been obtained and with considerable power.

In Figure 6 is shown an alternative method of carrying out this experiment. Here L_1, C_1, R_1 constitute an artificial antenna having the same inductance, capacity and dissipative resistance as the actual antenna The equality of these quantities is tested in a manner similar to that given above.

The three principal methods in use at the present time for determining "radiation resistance," arranged in order of increasing precision, are the following:

(a) Inserting in the ground connection of the antenna a non-inductive resistance of such value that the current in the antenna is diminished in the ratio of one to the square root of two The additional resistance is then taken as equal to the non-conservative "radiation resistance." Austin has given a correction which must be made for the damping of the primary or exciting circuit.

(b) Determining from the resonance curve of the antenna by the Bjerknes method the damping factor and calculating therefrom the apparent "radiation resistance."

(c) Replacing the antenna by an artificial antenna of identical effective inductance and capacity, and ascertaining what non-inductive resistance must be inserted in the artificial antenna to secure in it the same current as formerly flowed in the actual antenna.

We have appended for the convenience of the reader the following list of important articles and references dealing with this matter.

H. Hertz, Electric Waves, Page 150, or.

Wiedemann's Annalen, Vol. 36, 1889, Page 81.

M. Abraham, Die Theorie der Elektrizität, Vol. 2, Page 70.

R. Rüdenberg, Annalen der Physik, Vol. 25, 1908, Page 446.

P. Barrecca, Jahrbuch der drahtlosen Telegraphic, Vol. 4, 1910, Page 31.

C. Fischer, Annalen der Physik, Vol. 4, 1910, Page 979.

J. A. Fleming, Proceedings Phys. Society, Vol. 23, 1911, Page 117.

M. K. Grober, Physikalische Zeitschrift, Vol. 12, 1911, Page 121.
C. Fischer, Physikalische Zeitschrift, Vol. 12, 1911, Page 295.
L. W. Austin, Physikalische Zeitschrift, Vol. 12, 1911, Page 924.
L. W. Austin, Jahrbuch, etc., Vol. 5, 1911, Page 419.
L. W. Austin, Journal Washington Academy, Vol. 1, 1911, Page 9.
P. Barrecca, Jahrbuch, etc., Vol. 5, 1911, Page 285.
J. Erskine-Murray, Jahrbuch, etc., Vol. 5, 1911, Page 499.

ALFRED N. GOLDSMITH, Ph. D.

DISCUSSION.

PROF. PUPIN. It will be noticed that this method does not require much power, for the radiation law is independent of the E. M. F. impressed. To avoid the evil effects of high inductance the electro-static telephone might be used as a detecting device.

DR. GOLDSMITH. This method is an excellent illustration of the courage needed to transfer ideas from one field of research to allied fields. It is evident that for the higher frequencies the alternator cannot be used. For this purpose the Poulsen arc converter without magnetic field and supplying but little energy and that of sinusoidal wave form can be employed. In order so far as possible to avoid the presence of resistance in the inductances in the bridge and antenna, they should be wound with "litzendraht," that is multiply stranded separately insulated wires of many strands of small individual diameter.

L. ESPENSCHIED. A properly adjusted buzzer used by the method of "Stosseregung," that is, impulse excitation, might be employed to produce the necessary feebly decaying alternating currents.

R. H. MARRIOTT. They are frequently so employed in testing detectors of various types. I wish also to call attention to the fact that in practical radio work there are other losses than those due to actual radiation and to heat. We get direct losses to ground and leakage losses.

PROF. PUPIN. They will appear either in R_1' or in R_1'', but not in R_1'''. Are they not very small in proportion to the radiation?

R. H. MARRIOTT. There are cases where I am not sure about that.

PROF. PUPIN. The reason they must be so is this. Suppose we take the length of wire which formerly made up the antenna and wind it into a coil. Determine the decrement of the current then obtained in this wire. You will have the same wire and the same leakage and an approach to equality in the other conditions. But it will not radiate.

If a free alternating current is started in this coil it will last a long time and be very persistent, that is, the damping will be very small. The open antenna has very much larger damping because of the radiation resistance and unless it leaks very badly, I could not imagine the resistance due to leakage being more than a very small fraction of the radiation losses.

R. H. MARRIOTT. The leakage losses from brush discharge in a powerful station must be considerable.

J. MARTIN. I should like to ask Prof. Pupin the value of an apparently simpler method of which I have recently read. It consists in placing in the aerial a sufficiently large non-inductive resistance to reduce the square of the reading of the hot-wire ammeter to one-half its previous value. The value of the resistance is then equal to that of the radiation resistance.

As to the values found by actual measurements, eight ohms or less is not uncommon. In the case of the Fessenden 25 K. W. transmitter recently installed on the battleship Connecticut, I had to prepare for a current of 50 amperes.

As to the question suggested by one of the members relative to the value of radiation efficiency, I can refer to an article by Kiebitz, translated in the London Electrician of April 30th, 1909, page 99:

Supply current; watts	1000
Secondary resistance, watts	200
Secondary discharge and heating in coil, watts	750
Spark, watts	20
Condenser and secondary heating, and brush discharges, watts	20
Aerial, earth, ozone	9
Leaving for radiation	1

PROF. PUPIN. Provided the current in the antenna is sinusoidal and that the extra non-inductive resistance is inserted at an antinode of current, the method outlined above should be a good first approximation.

HIGH TENSION INSULATORS FOR RADIO-COMMUNICATION.

By Stanley M. Hills.

There is hardly a piece of electrical apparatus in which some form of insulation is not to be found, and yet until very recently one might say that but a very small amount of consideration had been given to insulation problems.

The demand for compactness and consequent reduction of space factor, and the use of high voltages, together with the introduction of radio-telegraphy were perhaps the chief factors which led to the further development of insulation and insulators.

The most usual high insulators met with in radio work are glass, porcelain, mica, micanite, air, oil and patent compositions such as electrose.*

A substance insulates by the possession of three distinct properties:

I. The ability to stand mechanical and electrical stresses due to or caused by the potential or voltages stress applied.

II. Small conductivity, so that a negligibly small current can flow through it, and leak away.

III. The power to resist any chemical action that may be caused by the application of the voltage stress.

The first property is termed by Maxwell the dielectric strength of the insulator, the second property being termed the ohmic resistance. There is no direct relation between these two properties; for a low ohmic resistance does not necessarily imply a low dielectric strength, neither does a low dielectric strength indicate a low ohmic resistance. The chief value of the ohmic resistance test is the indication it gives of the moisture-resistant qualities of the insulator under consideration. In spite of the importance of the subject, but little information has been published, comparatively speaking, and that which has been published is widely scattered among the proceedings of many scientific societies and in the columns of the technical journals.

* See Editorial Notes for more recent materials.

This paper has been written with a view to presenting in as concise a form as possible information regarding the properties of insulators which the members of the Institute of Radio Engineers are likely to employ.

A good insulator must possess the following properties:

1. High Disruptive Strength.

2. High Insulation Resistance.

3. Physical properties which are permanent over a wide range of temperature.

4. Non-volatility.

5. Should be non-hygroscopic.

6. Must be able to resist the action of water, acids, alkalies, and oils, and particularly for radio work, the action of sea spray.

7. Should be fireproof.

In addition, in certain cases, other requirements have to be met, such as mechanical strength for strain insulators, pliability for cables, etc. For radio work the insulation required may be divided into two main headings, namely:

(a) Antenna Insulation.

(b) Condenser Insulation.

(Transformer and generator insulation, falling under the consideration of the firm making these machines, are usually not of prime importance to the radio-engineer.)

The insulators in common use for antenna and condenser work are:

(a) Antenna Insulation.

1. Glass. 2. Porcelain. 3. Sulphur. 4. Patent Compositions.

(b) Condenser Insulation.

1. Air. 2. Compressed air. 3. Hard rubber. 4. Glass. 5. Hard Vulcanized Fibre. 6. Mica. 7. Oil. 8. Paraffin Wax.

It is the purpose of the author to discuss the physical and electrical properties of these insulators, to make a comparison between these properties, and to give the requirements of the work for which the insulators are usually used.

A considerable amount of confusion and argument has been caused by the misuse of the terms "dielectric strength," "electric

strength" and "Specific Inductive Capacity," and we shall therefore define what meaning we wish to convey when using these terms.

In this paper the term dielectric strength is used when referring to the voltage which must be applied to a definite sample of the material in order to cause its rupture; and the term specific inductive capacity is used to define the energy storage capacity of a sample of insulation as compared to air or the ether.

The breakdown voltage of an insulator depends upon many conditions. The principal ones are:

a. The shape of the electrodes with which the voltage stress is applied.

b. The temperature, and facilities for heat radiation.

c. The thickness of the sample under test.

d. The length of time during which the stress is applied.

e. The wave form of the source of voltage supply.

f. The time rate of application of the stress; that is, whether the stress is applied suddenly, or gradually.

g. The condition of the sample as to dryness.

From this wide range of conditions it can be seen that in making comparisons between samples of insulation, considerable care must be taken to ensure that all samples are tested under precisely similar conditions

The nearer the shape of the electrodes approaches that of the needle point, the lower will be the breakdown voltage; and, generally speaking, the higher the temperature the lower the breakdown voltage.

The breakdown voltage per unit of thickness decreases as the thickness of the sample increases; for example, a sample of mica 1/100 cm. thick will breakdown at about 200,000 volts per millimeter, whilst a sample one cm. thick will perhaps rupture at a pressure of 65,000 volts per mm. All insulators do not vary so much as this, but the safest way to obtain results for design work is to test several samples of various thicknesses, and plot a curve showing the relation between thickness and breakdown voltage.

When a dielectric or insulator is under electric stress the temperature rises rapidly at first, the amount of rise depending on the facility for heat radiation. Then the rate of change of temperature slowly decreases until finally the temperature becomes constant. When a direct current stress is applied, this increase of temperature is due to ohmic resistance losses, while if an alternating current stress be applied, the rapid alternations

of the field cause dielectric hysteresis, an effect comparable to the hysteresis met with in iron. Such hystersisis always causes a rise of temperature.

As the stress applied is increased, the temperature of the insulator increases. Often heat is generated at a greater speed than it can be radiated thereby causing the material to burn or char, and rupture or breakdown occurs. A rupture is more frequently caused by this phenomenon than by the voltaic stress which is applied.

For this reason it is generally unwise to subject finished pieces of apparatus to unnecessarily severe or prolonged tests, as these may cause slight charring, which, altho it does not cause a breakdown at the time of the test, will do so sooner or later.

Owing to the fact that the temperature increases with the stress, the losses in a dielectric are not strictly proportional to the square of the voltage, but increase at a slightly greater rate than the square of the voltage.* Since the temperature enters into this question, the initial temperature of the dielectric and surrounding media and the facilities for heat radition also have considerable influence in determining the values of the losses which take place.

The specific inductive capacity or dielectric constant has a considerable effect on the insulation strength of any insulating material which consists of a mixture of various substances The voltaic stress divides itself in the inverse proportion to the specific inductive capacities of the materials. In 1898 Professor R. A. Fessenden performed an experiment which clearly illustrated this phenomenon. He took two electrodes, A and B, Figure 1, and placed them one centimetre apart, applying an alternating current at a pressure of 10,000 volts. This gave a fall of potential of 10,000 volts per cm., which was the maximum the air could withstand without brush discharge. Next he introduced between the electrodes two plates of glass, C and D, Figure 2, of specific inductive capacity 8, each plate having a thickness of .25 cm. As stated, the stress was divided in the inverse proportion to the specific inductive capacities of the air and of the glass. That is the air has now to withstand $\frac{8 \times 10{,}000}{9} = 8890$ volts across a thickness of 0.5 cm.

At every reversal of the voltage a spark passed. This quickly raised the temperature of the glass, and, by lessening its insulating

* See Editorial Notes.

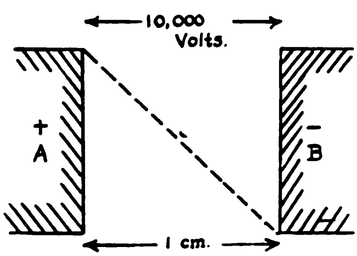


Figure 1.

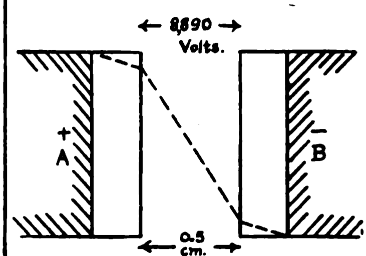


Figure 2

Figure 3.

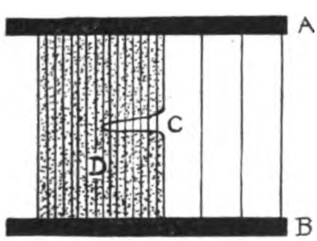
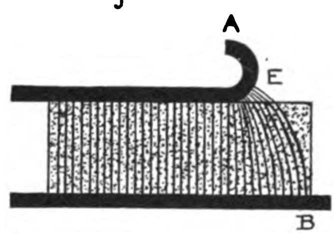


Figure 4.



quality, finally caused an arc to form between A and B. Thus where the layer air had previously withstood 10,000 volts to the cm., it now broke down, owing to the introduction of a material of much higher specific inductive capacity. The experiment shows that it is highly important that insulating materials which are made up of a number of substances should consist of either a thoroughly homogeneous mixture or that when applied in the form of layers, the specific inductive capacities should be so arranged that no sudden changes in the stress gradient are caused.

We shall now consider various dielectrics in detail.

AIR AND COMPRESSED AIR. Air is used as an insulator in transformers and condensers, more generally in the latter. An air condenser is the most simple form which can be obtained. It is efficient, the only loss which takes place being the energy which is spent in brush discharges which take place between the edges of the conductors. The dielectric strength of dry air is high, being in the neighbourhood of 3,700 to 4,000 volts per millimeter. The main objection to air condensers is their size, which must be large if any appreciable amount of energy is to be stored. Professor R. A. Fessenden has for some time used compressed air condensers, and by this means has been able to retain the advantages of the air condenser and yet largely eliminate their chief disadvantage. This is due to the fact that the dielectric strength of compressed air is much greater than that of air at atmospheric pressure. Thus he reduced the size for a given voltage and capacity. For ordinary practical purposes, it may be taken that the dielectric strength of compressed air is directly proportional to the pressure. This is not quite true theoretically, except where needle point electrodes are used.

In practice it is a difficult task to avoid having a point somewhere, and for practical work the author prefers to rely on the needle point test in preference to a test between two spheres. The sphere test usually gives higher values to an extent which depends upon the diameter of the spheres.

In March, 1909, Mr. E. A. Watson read a paper on "The Dielectric Strength of Compressed Air" before the English Institute of Electrical Engineers, and from a long series of experiments he deduced the following empirical formula connecting the dielectric strength and air pressure:

Dielectric strength in Kilovolts per cm. at a temperature of 17 degrees C. $= 20 +$ (25.6 times Air Pressure in Atmospheres).

From this the author has obtained the figures given in Table 2. So far as has been determined by experiment, this formula holds only up to a pressure of 15 atmospheres, though there is but little doubt that the formula would hold at least approximately for higher pressures.

When very high voltages are used considerable trouble is met with because of brush discharge. This is largely caused by the accumulation of dust which settles on the plates and forms points from which the brush discharge takes place. When using compressed air condensers it is advisable to be very careful to keep the plates clean and to ensure the use of dry air by the employment of suitable filters. One great advantage of air as a dielectric is that if a puncture occurs an automatic self-healing process takes place (oil being the only other dielectric which possesses this valuable property). Another advantage is that air does not deteriorate from aging effects.

INSULATING OILS. With the advent of high voltage work came the introduction of various oils for use as insulators. As a general rule, pure mineral, vegetable, and animal oils form good insulators, but their insulating properties depend largely on their purity.

To the eye, clear and almost colorless oils are likely to give the impression of purity; but a dark colored oil is often the purer because the clarifying process may entail the use of chemicals, small quantities of which may be left behind and thus reduce the insulating quality of the oil. Dust, especially metallic dust, moisture and sulphur are the three most destructive impurities. Altho sulphur by itself is an insulator, its presence in insulating oil is often the cause of a breakdown; particles of dust are likely to become "electrically charged," and when in that state will line up between points where there is a difference of potential, thus forming a conducting path and causing a spark to pass.

The oils obtained from the Western States are particularly likely to contain sulphur. The insulating strength of oil usually increases with the frequency of the applied voltaic stress; a property which is valuable in radio work, and one which is not met with in solid insulators.

Great care must be taken to eliminate moisture in any insulating oil, as it has a most deleterious effect on the insulation strength. The presence of 5 per cent. of moisture will often reduce the breakdown voltage by 50 per cent. A very good test for the presence of moisture in oil is to mix a small quantity of

the oil with a little powdered anhydrous copper sulphate. The presence of even a small quantity of moisture will be indicated by a blue coloration of the oil.

Mr. Skinner, in a paper read before the American Institute of Electrical Engineers, gave the following specifications for a good transformer oil:

1. The oil should be a pure mineral oil obtained by the fractional distillation of petroleum and unmixed with any other substances and without subsequent chemical treatment.

2. The flash test of the oil should not be less than 180° C, and the burning test not less than 200° C.

3. The oil should not show an evaporation of more than 2 per cent. when heated at 100° C for eight hours.

4. The oil must not contain moisture, acid, alkali, or sulphur compounds.

5. It is desirable that the oil be as fluid as possible, and that the color be as light as can be obtained in a pure untreated oil.

Mineral oils usually evaporate slightly at temperatures a little below the flash point, and rapidly at temperatures above flash point.

One great advantage possessed by oil is that if a spark passes the puncture is self-healing, the only detriment being the particles of carbon which are left and which, if they become too plentiful, may cause the same trouble that dust does.

Insulating oils have a somewhat peculiar effect on mica. They tend to reduce its insulating value, but apart from that they are not harmful to insulators.

The dielectric strength of insulating oils increases with a rise of temperature, a property which is very valuable. On the other hand, the specific resistance decreases with temperature rise.

MICA. In many ways mica is a good insulator. It possesses a high dielectric strength, is unaffected by heat; but it suffers from mechanical disadvantages, owing to the fact that it is not flexible and is very easily split and broken. Mica is an anhydrous silicate of aluminum and potassium or sodium, the transparent samples being composed largely of aluminum and potassium and the less transparent ones contain magnesia and iron. The transparent varieties are usually the better insulators, but the black spots often noticeable in mica are not a source of weakness, as might be assumed at first thought. The chief disadvantages of mica are its lack of uniformity in dielectric strength and its great ten-

dency toward surface leakage. The green shades of mica are usually the softest, whilst the Canadian "White Amber" is the most flexible. Insulating oil reduces the surface leakage, but also reduces the dielectric strength.

MICANITE. Micanite consists of layers of mica held together by an insulating cement. This cement is usually of secret composition, as it is the key to the quality of the ultimate product. At one time pure shellac was often used as a cement, but this is not advisable, as shellac has a low, softening temperature, is hygroscopic, and likely to deteriorate rapidly with age.

When heated, micanite can be readily moulded into various shapes, and thus the disadvantage of inflexibility of pure mica is overcome. Micanite is usually made up with cloth or paper as a backing, in addition to the cement, and the dielectric strength varies with the form of backing used. Reference to Table 1 will illustrate this point.

PARAFFIN WAX. This substance can be used both in the solid form and, when impregnated, in various forms of paper. It has a low, softening point, and is mechanically weak, being readily scratched with the finger-nail. It has a moderately high dielectric strength, and paper impregnated with it is often used in condensers. Paraffin waxed paper frequently cracks when bent in a cold state.

HARD RUBBER. This material has a high dielectric strength and is much used for bushings, terminal blocks, and small parts of apparatus. It is somewhat susceptible to surface leakage, especially when highly polished. It can be machined, but it is somewhat treacherous and is easily split and cracked.

Hard rubber deteriorates with age and exposure to the atmosphere. Though the polish does to a certain extent increase surface leakage, the oil used in the polishing process tends to form a preserving film over the surface of the sample. Hard rubber will not withstand high temperatures.

VULCANIZED FIBER. This is another material often used for bushings and terminal blocks. It has not a very high dielectric strength. It is brittle and may split and warp when exposed to changes in temperature, and is also very hygroscopic.

GLASS. Glass has a high dielectric strength, but possesses other disadvantageous properties which reduce its value as an insulator. It has a very large surface leakage, and is very hygroscopic. Being slightly soluble in rain water, there tends to be produced a roughened surface on which dirt can collect and

form a conducting path, thereby increasing the already large amount of surface leakage. Glass will crack and shatter when violently struck and is not mechanically strong. Being transparent any flaws that are present are readily discernible. Lead is often present in glass, and the insulating value is thereby reduced. Plate, annealed and crown glass are the best for insulating properties. Glass is acid-proof and will withstand normal temperatures.

PORCELAIN. Porcelain has a higher dielectric strength than glass and less surface leakage. Cheap porcelain is often extremely hygroscopic and only the very best quality should be used for insulating purposes; this caution being particularly important for radio work. The author has found some samples of porcelain to absorb 1 to 2 per cent. of their weight of water. Porcelain for insulating work should not absorb moisture and should give a brilliant vitreous fracture when broken. Two tests may be performed to demonstrate this quality. A good porcelain when fractured will not give a flowing stain when ink is applied to the fracture. If the tongue be applied to the fracture, a vitreous porcelain will feel cold and glassy, while a poor porcelain will give a rough absorptive feeling like chalk or blotting paper. Porcelain essentially consists of English clay and china clay, with a small percentage of Tennessee clay, felspar and quartz. The clays form the body, giving mechanical strength, the felspar and quartz act as a flux and help to make the mass thoroly homogeneous. The most critical operation in the manufacture of porcelain is the baking process, the temperature required being about 2,700° F. If made too hot, the porcelain becomes porous, while if not sufficiently heated the clay does not become properly vitrified. For use as an insulator the porcelain must be thoroughly homogeneous, vitrified and solid. Unfortunately porcelain is opaque and flaws cannot be visually detected. If the porcelain is not homogeneous and vitrified it depends on the glaze for its insulating value, and once the glaze is fractured the insulating value is practically reduced to zero. Porcelain in comparison with glass is strong and tough, the surface does not weather badly, and, barring breakage, the insulating value is practically permanent. Generally speaking, good porcelain is comparatively non-hygroscopic. Porcelain varies greatly in quality. The German Hermsdorff porcelain is a particularly good variety.

SULPHUR. Sulphur has a moderately high dielectric strength, is soft and brittle, has a low melting point, and when

hot is very volatile. Owing to its low melting point, it is often used as an insulating cement, and when mixed with finely powdered glass it is very suitable for that purpose, especially with porcelain insulators. Sulphur has a bad effect on insulating oils, and should not be used in places where it is likely to come into contact with them.

LAVA. This substance is not, as often supposed, of purely volcanic origin. It is a form of magnesium silicate bearing the chemical formula H_2 Mg_2 Si_4 O_2. It can be machined when in its natural state. When it is to be used for insulating purposes, it is first machined into the desired shape, and then baked at a temperature of 2000° F. The baking process makes the lava very hard and capable of withstanding a high crushing or compressive stress. It is free from metallic salts, and does not change in shape with changes in the surrounding atmosphere. Lava is slowly soluble in strong hydrochloric acid, but is otherwise acid and alkali-proof. It will stand a high voltaic stress without breaking down.

AETNA. Aetna is a patent composition used in the form of strain insulators. It has a fair dielectric strength, a tensile strength of 2.46 tons per square inch, and withstands the action of heat, but Mr. H. D. Symons reports that he has sometimes found it to be brittle, and an absorption test shows that Aetna absorbs 3.17 per cent. of its own weight of water at a temperature of 120° F.* The surface resists weathering well, and it forms a satisfactory strain insulator.

LAVITE. This is a patent material, of light color, and has a high dielectric strength. It is hard, in fact so hard that it can be used to scratch glass. It is unaffected by temperatures up to 1000° C. It is acid and alkali-proof, but a mixture of strong hydrochloric and nitric acids in the proportion of one to three will, when the solution is warmed, attack this material. It can be machined and turned, and will withstand a very high compressive strain. Lavite is suitable for the manufacture of tubes, bushings, and other small parts, the only disadvantage being that it cannot be made into large pieces of apparatus.

MARBLE. The use of marble as an insulator is practically confined to switchboards. It is liable to be hygroscopic and the condensed moisture on its surface produces and aids surface leakage. For good insulation, it should be free from metallic

* H. D. Symons, Insulation and Insulators, Technics, Vol. 3.

veins. Usually the softer qualities of marble have the highest dielectric strength. It is liable to crack with a knock or a jar and is somewhat treacherous in behavior when being machined.* The specific gravity of marble often gives considerable indication of its insulating properties. Generally speaking:

1. The greater the specific gravity the lower the absorption of moisture.

2. Mechanical properties are good in the inverse ratio to the electrical properties.

3. The higher the specific gravity the lower the breakdown voltage.

4. The specific gravity increases as the crushing stress increases.

Marble, which will absorb more than 0.5 per cent. of its own weight of moisture after 24 hours' immersion in cold water, is not of much use for electrical work where high voltages are employed.

ANTENNA SUSPENSION INSULATORS. Suspension insulators, whether of some patent composition, glass or porcelain, should be designed to fulfil the following conditions: They must afford an efficient means of insulation in all weathers, which require them to be unaffected by fogs, dusty deposits that may be in the atmosphere, rain, acids or alkalies and salt water spray. The design and choice of the overall dimensions should be arranged so that a compromise is effected between the leakage distance and surface area, such that a maximum leakage distance is obtained with a minimum surface area.

The potential gradient from the antenna to the ground should be made as gradual as possible in order to reduce the risk of "arcing over" and "brush discharge" to a minimum.

All cemented joints must be so arranged that they are under a compressive strain, in fact, whenever possible, it is best to have the whole insulator under compressive strain, as insulators of this type are capable of standing a greater stress when so arranged.

With regard to insulators made of patent compositions it is important to ascertain whether they are affected by salt water and whether their surface roughens on exposure to the atmosphere. If they are to be used in tropical regions the effect which temperature has upon them should be investigated, as such com-

* Hills and German, paper on "Dielectrics and Dielectric Testing," read before Junior Institute of Engineers, England, March, 1909.

positions are liable to contain shellac or other gum as a form of binding cement, and may soften in tropical temperatures.

CONCLUSION. The tendency of the age is to cheapen production and reduce the cost of both labor and material, but it is extremely unwise to be sparing of expense where insulation is concerned. In a way insulation may be said to be a keystone to the whole, i. e., if the insulation breaks down the remainder of the parts is useless. At the present time it is impossible to give standard values for the strength of insulating materials; they cannot be depended upon like the stress and strain values of iron and steel. Insulation is so greatly affected by changed conditions, and different batches of the same material are liable to be considerably different in insulating value, so that a high safety factor should always be used. Further, age invariably causes deterioration of insulation, especially in exposed positions. In high voltage, radio-frequency work very large static strains and stresses are liable to be produced. Often the possibility of these stresses arising is entirely overlooked and when the safety factor has been reduced to a minimum, a breakdown inevitably occurs. In this class of work it is advisable to allow a safety factor of ten, in order to be certain of safety. The perfect insulator, so far as our knowledge guides us, "Non-Est," therefore it is necessary to sum up the most important conditions to be fulfilled and select the insulator which most nearly satisfies those conditions.

Insulation is a complex subject, and when the field is narrowed down to high insulators there is much that might be written. A short bibliography has been appended with a view to assisting those who wish to study this subject more fully.

TABLE NUMBER 1

Dielectric Strength of Various Insulating Materials

Material.	Dielectric Strength per 0.001 of an Inch in R.M.S. Volts A.C.
AETNA	35
ASBESTOS	125
BRISTOL BOARD	180
CELLULOID	90
FIBRE (Vulcanized)	175
LAVA (Talc.)	125
LAVITE	200
LEATHEROID	150
LINSEED OIL (Boiled and impregnated on Bond Paper)	600
MICA (Pure White)	3000
MICANITE (Cloth)	300
(Flexible Cloth)	190
(Paper)	420
(Flexible Paper)	300
MICA (Plate)	1000
(Flexible Plate)	700
OILED CAMBRIC	650
OILED PAPER	800
PARAFFINED BOND PAPER	900
PRESSBOARD	125
PRESSPAHN	300
SHELLACKED CAMBRIC	35
VULCANITE	840
HARD RUBBER	900
GLASS (Common)	203
(Head)	140
(White Alabaster)	290
(Plate)	280
PORCELAIN	1800
HERMSDORF HARD PORCELAIN	2500
LINSEED OIL	1200
" (Boiled)	1600
OLIVE OIL	1650
SPERM OIL	1300
"TRANSIL" OIL	2000
VASELINE OIL	1500

Values compiled from various sources—

Hobart & Turner on "Insulation of Electrical Machines."

H. D. Symons on "Insulation and Insulators."

J. A. Fleming on "Electric Wave Telegraphy."

S. P. Thompson on "Dynamo Electric Machinery."

S. M. Hills and T. Germann on "Dielectrics and Dielectric Testing."

N. B.—No hard and fast figures can be given for the dielectric strength, because samples and conditions of test vary considerably. Considerable care has been taken in compiling the above table, and the values given are on the "safe side," higher values often being obtainable.

TABLE NUMBER II.

DIELECTRIC STRENGTH OF COMPRESSED AIR, AT TEMPERATURE OF 17 C.

Air Pressure in Atmospheres.	Dielectric Strength in Kilovolt Per C. M.
2	71.2
4	122.4
6	173.6
8	224.8
10	276.0
12	327.2
14	378.4

Figures calculated from formula given by A. E. Watson, proceedings, English Institute of Electrical Engineers, Vol. 43, page 132.

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Properties of Switch and Transformer Oils, Electrician, April 1st, 1910.

EDITORIAL NOTES.

Since the above lecture was written a number of new insulators have appeared. As typical of this new class may be taken BAKELITE and CONDENSITE. They are resinous or amorphous products resulting from the action of phenolic bodies upon formaldehyde or other methylene compounds. They are usually light brown in color and even translucent, but may be produced in opaque forms of various colors. The property rights in the American patents have not as yet been judicially determined, but the principal claimants in America are Aylsworth and Baekeland. The materials can be produced in soluble forms, fusible or infusible. Frequently fibrous organic materials are impregnated with these compounds at high temperatures in the hydraulic press and then molded. The fibrous materials used are generally wood pulp or finely divided sawdust. Contrary to expectation, asbestos is not a suitable substance for impregnation because of its mechanical weakness and lack of elasticity. (The main object of adding the fibrous materials is to give flexibility and elasticity to the insulator. The phenolformaldehyde products are exceedingly

hard and resistant, have a high crushing strength, but are very brittle.)

The insulation strength of these products is remarkable. Baekeland states that paper impregnated with them and submitted to hardening under heat and pressure has shown an astonishingly high disruptive (puncture) test, averaging 77,000 volts alternating current on sheets one-sixteenth inch thick. This is 1,230 volts per mil, 1,232 kilovolts per inch, or 485 kilovolts per cm. The production of these substances is very considerable, more than one ton of Bakelite being made per day at present.

In treating dielectric hysteresis in the preceding article, it was stated that the dielectric losses depended on the n-th power of the voltage, where n was greater than 2. A detailed discussion of this matter will be found in a paper by Fleming and Dyke (Electrician, Feb. 3rd, 1911, page 658). The values of n there given are 2.15 and 2.61 for two different samples of vaseline oil, 3.5 for air (tho, of course, with a much smaller constant of proportionality in this case), and 2.42 to 4.24 for glass jars and plates.

A valuable discussion of the properties of compressed air condensers is given by Max Wien (Annalen der Physik, 1909, "On the Damping of Condenser Oscillations"). A type of compressed air coaxial cylinder condenser is there described, which is 100 cm. long, 6.5 cm. diameter, weighs 6 kilograms, has a capacity of 0.0017 mmf., and at normal working pressure of 15 to 20 atmospheres will withstand 40,000 volts across its terminals. The separation between the cylinders is about 3 mm. These values agree well with those given by R. A. Fessenden, namely, at 10 to 14 atmospheres pressure, the sparking voltage between plates 2 mm. apart was 28,500 volts. Such air condensers are found to produce no perceptible increase in the damping of a circuit in which they are placed, as compared with ordinary air condensers. It was found that Leyden jars added about 0.010 to the decrement, paraffin oil condensers about 0.001, and compressed air condensers less than 0.0002.

Methods of removing moisture from insulating oil without chemically changing the oil are given by S. M. Kintner (Electrical Journal, Vol. III, 1906). Filtration thru substances capable of combining with water and free acids is preferred to heating processes which may easily start an injurious decomposition of the oil.

There has been a marked tendency recently to standardize the

rating of insulators and the proper factors of safety under various conditions. Thus, the Allgemeine Elektrizitäts Gesellschaft of Berlin, following the designs of their engineer, C. Kuhlman, has placed on the market a series of insulators of standard specifications. The insulators used on 4,400 volts spark over at 22,000 volts (factor of safety = 5), those for 17,000 volts spark over at 50,000 volts (factor of safety = 3), and those for 77,000 volts spark over at 170,000 volts (factor of safety = 2.2). The reason for the diminution of the safety factor with increasing voltage is that excess voltages depend upon current surges, and the currents on extremely high tension installations are generally limited to small values. Complete details of such a series of standardized insulators for 750 to 200,000 volts are given by W. Fellenberg (Elektrotechnische Zeitschrift, 1912, pages 640 and 684).

The use of insulated steel towers for antenna supports has given rise to a new insulation problem, namely the obtaining in insulators of the necessary mechanical strength under great compressive stress. One method which has so far worked well in practice is used at the Bush Terminal station of the National Electric Signaling Company. There the massive steel towers, 150 feet high, are supported each by 25 glazed porcelain conical insulators, approximately 8 inches long. These rest on a heavy concrete base. There are also two anchoring blocks, each mounted on 10 such insulators. Another method is to be employed at the Transatlantic Station of the Hochfrequenz-Machinen Aktiengesellschaft of Berlin (Goldschmidt alternator system) at Tuckerton, New Jersey. The tower, of steel 820 feet high, will rest on three spheres of a glass-like composition, the diameter of each sphere being about 3 feet.

Following somewhat different methods from those given in the present paper, W. Petersen in an article on High Tension Insulation in Archiv für Elektrotechnik, 1912, Vol. I, Page 28, draws certain conclusions which are of interest in radio-transmission.

In Figure 3, D, is a piece of porcelain placed between the metal plates A and B. The difference of potential between A and B is taken as not far from that value which would cause a brush discharge across AB. The lines of electric force are of course relatively crowded in the porcelain which has a higher dielectric constant than air. But its strength enables it to stand the strain. If now there be at C a crack or pore in the porcelain, the number of lines of force passing through it will not be very different

from the previous value, hence the strain on the air in this cavity will be far greater than on that outside. Consequently the air in the crack will be ionised and a spark discharge across the gap will speedily follow. To avoid this "crater" action, care must be taken to use only perfectly smooth and flat pieces of insulating material, free from cracks and pores, in such situations.

If plate A is curved at its end as shown in Figure 4, and between the plates A and B is placed a sheet of insulator, it is most likely to be cracked at B. The reason will be seen when the distribution of the lines of electric force near B is examined. Those which are refracted as they pass from the insulator to air near E are so closely crowded together in the air that ionisation begins, with brush discharges, roughening of the surface at E, and eventual breakdown. The greater the dielectric constant of the insulator, the worse it behaves in this matter of the excessive crowding of the lines of force and consequent strain produced by the refraction at the boundary surface of the material.

ALFRED N. GOLDSMITH, Ph. D.

DISCUSSION.

Robert H. Marriott.—The problem of insulation in wireless is, as Mr. Hills says, a very important one. Probably every radio-engineer or operator present can cite a case or cases wherein a wireless transmitter or receiver had its efficiency materially lessened by poor insulation, and those of us actively engaged in wireless should be able to profit by this paper, which covers a considerable scope in few words.

Mr. Hills does not mention hard rubber as a material for antenna insulation. However, it is and has been used for this purpose in the form of rods about 1″ in diameter and 1 to 2 feet in length, with screw eyes in the ends for fastening ropes or wires. These rods have given considerable trouble, due to their absorption of moisture and their surface becoming wet from rain, snow, fog or local precipitation when they are colder than the surrounding air. And the eyes in the ends of the rods frequently straighten out.

I have improved these insulators on some occasions by substituting welded eyes, varnishing the hard rubber (which tends to keep it from absorbing moisture), and by fastening a copper cone or cup to the upper end of the insulator in such a way that it protects the hard rubber from rain, snow and fog, and to some extent from local deposition of moisture.

Wood is frequently used for strain insulators in the guys, and even rope has been used. Both of these materials in the form commonly used have been bad, at least mechanically, because when the weather caused them to rot or split they pulled apart.

A wooden strain insulator at Manhattan Beach, composed of two parallel 2″ x 4″ oak timbers that apparently had been boiled in asphaltum, and which was subjected to a tension strain in the direction of the grain of the wood, pulled in two in the middle and dropped the "sky-line," thus crippling the station for several days. Other insulators of this form broke at Manhattan Beach, but usually through splitting out at the ends. These insulators had been subjected to the weather for probably four years. Furthermore the breaking of a rope strain insulator is said to have caused the tower to fall at Cape Hatteras.

In place of these wooden and rope insulators I have used insulation in the form of dead-eyes, such as the R. Thomas & Co. porcelain strain insulators, and where porcelain insulators with a large enough groove could not be obtained, ship-rigging dead-eyes of lignum-vitae or Indian-hedge were used. With these the strain becomes a crushing strain; and even if the dead-eyes ever did crush, the two loops in the guy would simply come together and the guy would remain strong mechanically.

In addition wood has been and is used for insulating radio transmitting and receiving instruments.

For example.—In a certain condenser jar rack containing two banks of jars, the outside coatings of the jars are connected by strips of copper tacked to the bottom of the wooden jar rack; the inside coating of one bank connects to one transformer terminal and a spark gap, while the inside coating of the other bank connects to the other transformer terminal and to ground through the helix. If the potential of the transformer is 20,000 volts, then the potential of the copper strips tacked to the bottom of the wooden rack may be high, say 10,000 volts to ground. The wooden rack and the floor become damp, both sides of one bank of

jars are then grounded, and the other bank takes approximately the potential load of 20,000 volts with only one thickness of glass, instead of two thicknesses to withstand this pressure. At the same time the capacity of the local circuit is doubled and therefore the local circuit is thrown out of tune with the antenna circuit.

Usually a jar will break in the bank that is doing the work. What happens then depends upon the experience of the operator. He will probably put in a new jar, losing considerable time and possibly some messages in doing it; then he breaks another jar. He may keep on breaking jars until he gets disgusted and gives up working the set.

Or, he may close down the spark gap until he gets a spark that does not break jars. He may be using the same amount of power, but his transmitter circuit is certainly out of tune with his antenna circuit, and little or no current will be transferred between the circuits with the general result that probably he will not send very far.

In the meantime, the jar rack may or may not show indications of burning where he will notice them. If he does see the burning he will probably do the right thing, i. e., scrape off the blackened part of the jar rack, set the rack legs on porcelain, glass or some other good insulator, put in a new jar and go ahead without more trouble.

I have obviated the grounding of the jar rack by fastening inverted Western Union insulators to the bottom of the legs, screwing the insulator pins to the inside of the legs.

Insulators frequently give trouble because they are colder than the surrounding air, causing the air to deposit moisture on the insulator. This can be stopped sometimes by simply warming up the insulator. For example, the muffler is short circuited and the operator should hold down the key until the muffler becomes warmer than the surrounding air, and the moisture evaporates. He no longer has a short circuit unless the muffler is dirty or is made of some material that will carbonize.

In radio-telegraphy we deal with high frequency alternating currents, so that when we want to keep rapidly alternating current from escaping, the insulator used for that purpose must not only be of proper ohmic resistance and dielectric strength, but it must be of low electrostatic capacity. An example of bad insulation with regard to the electrostatic capacity of the insulator

is to be found in the twin wires used frequently for connecting the two leads of a loop antenna from the anchor spark gap to the antenna switch.

These twin wires may or may not have sufficient highly resistant material between them, but their electrostatic capacity is comparatively high and as one of them is connected directly to ground, considerable current will flow from the other wire to it instead of passing through the tuner, so that the signals are weakened.

RECENT DEVELOPMENTS IN THE WORK OF THE FEDERAL TELEGRAPH COMPANY.*

By LEE DE FOREST, Ph. D.
Engineer of the Federal Telegraph Co.

The Federal Telegraph Company is unique in several respects. Among these, it enjoys the distinction of employing no press agents. Consequently in the East almost nothing is known of what is being done in the West. This is, of course, regrettable from a technical standpoint.

The present chain of stations of the company comprises those at Seattle, Portland, Medford, Central Point, Sacramento, Phoenix, San Diego, El Paso, Fort Worth, Chicago and others. Tho messages have been sent from San Francisco to Chicago, the service is not of the same character as that maintained on the Pacific Coast, which latter is strictly commercial. The largest of all these stations are those at San Francisco and Honolulu. Each of these has a power of 40 kilowatts, which is to be increased to 60 kilowatts.

We operate under the Poulsen patents. But the apparatus imported from Denmark in 1910, showed many commercial defects and lack of reliability. The cooling appliances were inadequate, and the insulation faulty.

The system, as now in use, is the simplest imaginable, particularly at the transmitter end. Referring to Figure 1, E is a direct current generator of 500 to 1,000 volts or even more, D are choke coils intended to prevent the alternating current from the arc flowing back to the generator and also intended to keep the generator direct current constant, A is the arc itself, B a tuning or loading inductance, and T the antenna. The arc itself plays between a copper positive electrode and a carbon negative electrode. It is always water cooled. It is in an intense magnetic field, and the atmosphere surrounding it is usually illuminating gas. Where this cannot be obtained, denatured alcohol is used instead. If desired, ether can be added to the denatured alcohol.

In this system the transmitting key is used, not as in most

* Lecture delivered before The Institute of Radio Engineers, November 6th, 1912, at Fayerweather Hall, Columbia University.

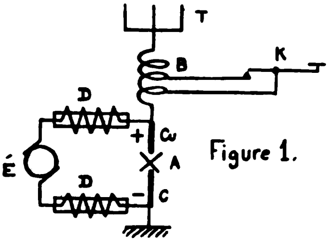


Figure 1.

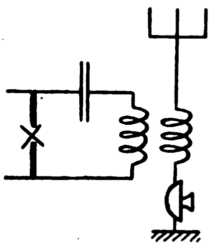


Figure 2.

Figure 3

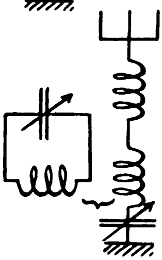


Figure 4.

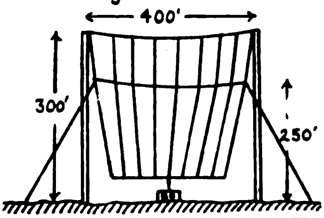


Figure 5.

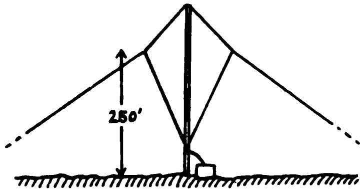


Figure 6.

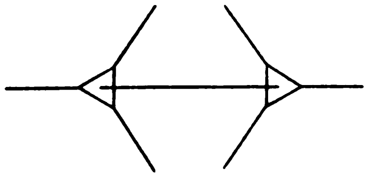


Figure 7.

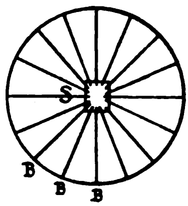
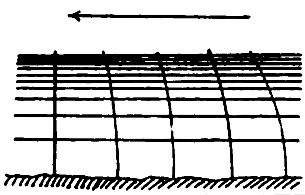


Figure 8.



stations to change the amount of energy emitted, but only to alter slightly the wave length. This is accomplished by connecting the key K as shown across one or two turns of the inductance B. When the key is pressed, the wave emitted is lengthened by say five per cent. So that all the time transmission is going on the antenna is radiating. This makes matters interesting but unsatisfactory for the amateur interloper who naturally fails to separate the two waves and interpret the messages. The wave not used for receiving, which is usually the shorter one, is termed the "compensation" wave, and the tuning at the receiving station must be sufficiently sharp to ensure that the compensation wave shall not be heard. It has been found that smaller amateur stations even in the neighborhood of the twelve kilowatt station cannot tune up to the longer wave, and this fact ensures their reception of what may be called reversed, and of course unreadable messages. We feel responsible for a state of thorough disgust on the part of said amateurs.

Furthermore, when in the immediate neighborhood of a powerful station of the Poulsen type, the received signals from other stations are considerably fainter when transmission is going on from the arc station. This may be due to either a surplus of energy passing thru the detector and rendering it insensitive; or to rendering partially opaque the transmitting medium by the undamped radiations.* I must admit that I cannot see just how this latter alternative can be the case tho it is difficult otherwise to explain the fact that even with the Audion detector the smothering effect is shown. For the effect mentioned, the arc may be as much as five miles distant, from the detector affected, and yet the signals from spark stations will drop to a marked degree.

It is of interest that the arc length or changes in it have practically no effect on the radiation, at least for telegraphy. For telephony, the constant conditions required are naturally more severe. For telephony, the double circuit arrangement shown in Figure 2 is used. The conditions being more critical in this case, the operator is required to watch the arc and keep it steady by occasional manipulation. The skill required is not great.

The receiving circuit ordinarily employed is shown in Figure 3. The coupling between the antenna circuit and the closed circuit is usually very loose. Thus with pancake shaped coupling coils such values of the angle between the coils as 88° are usual.

* See Editorial Notes at the end of this Lecture.

This is exceptionally loose coupling and ensures sharp tuning of a quality unattainable in spark systems. The tuning is remarkably sharp and we have done much work in the direction of eliminating damping in the receiving circuits. In particular we have found it necessary to avoid leaky condensers. And because of the undamped nature of the radiation we can get all the advantages of loose coupling.

The detector used is the ticker. The old-style ticker is an intermittent contact operated by an electric buzzer. The contacts themselves are between two gold wires, one of them fixed and the other attached thru an insulating piece to a diaphragm which is maintained in continual vibration by the buzzer armature. The contact wires are connected to the terminals of the tuning condenser in the closed tuning circuit and also to a considerably larger fixed condenser (value about 0.02 mfd.), which latter condenser is also connected to the low resistance receiving telephones. The action of the ticker is to permit alternating currents of large amplitude to build up in the secondary tuning circuit, and at more or less regular intervals to discharge the variable condenser thru the telephones producing at each discharge a click. The telephones are the ordinary 75 ohm double head band type. The note produced is not a pure musical one because the ticker cannot be arranged so as to interrupt the alternating current which charges the condenser at the same point of the cycle at successive interruptions. In consequence some clicks are louder than others and the note is not clear. It may be characterized as a hissing sound not altogether agreeable to the ear. If a rectifier is placed in the ticker circuit the note becomes much purer. But the signals are weakened.

The difference between the two waves emitted from the transmitter is small. Thus when the sending key is up the wave may be 3000 meters and it may be 3150 meters when the key is depressed.

An efficiency of twenty per cent. is considered good for the Poulsen transmitter. Tho this is only about one-third what is obtained by the use of the quenched spark, yet it is found that in practice we can work far greater distances than with the latter. This may be because the ticker telephone combination is by far the most sensitive and efficient detector in existence.

As examples of what is done as regular service, we work from Los Angeles to San Francisco, a distance of 350 miles with 12 kilowatts direct current. San Diego, with 5 kilowatts D. C.

is in communication with San Francisco at night. In the winter, the conditions are naturally much better. With 12 kilowatts D. C. we even work from San Francisco to El Paso in the daytime, a distance of 900 miles; not sufficiently continuously for commercial service but still very frequently; it being practically a daily performance.

The power utilized is limited by two considerations. One of these is the capacity of the antenna and the other is the voltage at the arc. We have worked up to 1200 volts but higher voltages than this are not excluded. As to the antennae, we have adopted as standard the double harp, twin-mast system. Its construction is clearly shown in Figures 4 and 5 which are those of a typical antenna of 0.005 mfd. capacity. The new antenna for the large South San Francisco station is supported by twin towers 440 feet high, 600 feet apart. The antenna capacity is here 0.012 mfd. Because of the low voltages employed, insulation difficulties are minimized. The type of tower now used is triangular in cross section and does not taper. For it special timbers have to be sawed. The plan of the guying system is shown in Figure 6. It will be seen that the construction lends itself to great rigidity. As the results of our tests with the 12 Kilowatt stations we have reached the conclusion that this type of masts and antenna is the best for our system. In some of our stations, we employ the flat top aerial of less height for receiving. But we regard the flat top aerial as inferior to the harp type. The harp type also has the mechanical advantage that by its use the danger of twisting of the spreaders disappears.

The ground employed is the radial type with connection to earth at outer points. It is shown in Figure 7, where S is the station house. The ground wires, which are buried two or three feet below the surface radiate in all directions, and are heavily bonded together at their outer extremeties, B.

At the South San Francisco station, the antenna current is about 40 amperes when 35 kilowatts is drawn from the direct current generator at 600 volts. The Honolulu Station is exactly like the South San Francisco one. The system as now improved is simple in operation and installation. As evidence of this, Mr. Elwell, Chief Engineer of the company, went to Honolulu on two days notice, and within sixty days the Honolulu station was in operation. And yet in this case there were considerable difficulties to be overcome. All the apparatus and supplies had to be shipped from San Francisco, and the Chinese workmen, who

were the only ones available, would not work at heights above one hundred feet. The distance covered by this station is 2300 miles. Since August, not less than 1500 to 2500 words of press have been transmitted daily. There are in addition a considerable number of paid messages. The rate is 25 cents a word against 35 cents of the cable companies. At the present time, we can operate up to 8 in the morning. When the new 60 kilowatt sets are installed, we expect to operate thruout the day.*

Between Los Angeles and San Francisco two to three hundred messages are sent every day, and this is strictly paid business, of a kind where accurate service is required. Of course, a certain type of customers is specifically catered to. Thus the California Fruit Growers Association do much business between Los Angeles and San Francisco. They demand a thirty minute service, that is, between sending the message and receiving the answer, and we have kept up that service for over a year now. This is a very strict test because these messages are all in an unpronounceable code. The Publishers' Press Association has also used our service from five to nine in the evening for a period of ten months or more.

There is another chain of stations at the following points: Chicago, Kansas City, El Paso, and Fort Worth. But these stations were equipped with too little power. The static in Texas is terrific and prevents service except in the daytime. At Chicago there are two 80 foot towers, 250 feet apart, placed at the top of a high building. They each carry 40 foot spreaders. The limit of power capacity here is 7.5 kilowatts, the limit in this case, being determined by the dimensions of the antenna. If greater power is desired, it will be necessary to use higher voltage.

An extremely interesting phenomenon has been observed in this work with undamped radiations of slightly different wave lengths. It is that at certain times daily, practically thruout the year, and under certain meteorological conditions, very surprising variations in the strength of the received signals occur when definite wave lengths are used, and only when these wave lengths are used. For example, the Los Angeles station works with a wave of 3260 meters and a compensation wave of 3100 meters, and the shorter wave is radiated continuously with the exception of the time during which the dashes or dots are being sent.

Now it will suddenly happen that the longer wave will become

* Since this paper was prepared 24-hour service, both ways, has been instituted and is daily successfully maintained.

very weak or even be entirely lost at the San Francisco station, distant 350 miles north, whereas it will be received with normal strength at the Phoenix, Arizona station, distant 300 miles to the east. Nevertheless the shorter compensation wave, which differs in wave length by only about 5 per cent., will be received in San Francisco with full strength, or even with greater intensity at times.

This phenomenon of the extinction of the waves occurs frequently, particularly at our stations near the Pacific Ocean; for weeks it was observed every evening and at other times was entirely absent. In consequence the operators have arranged to send on either of the two waves used.

The duration of this fading effect is often several hours after nightfall; then it suddenly vanishes and thereafter both waves have their normal intensity. This alteration of intensity is sometimes for one wave, and sometimes for the other, and rarely for both; and in the last mentioned case the operator can find a third wave on which he can receive clearly. Usually, however, one of the wave remains of normal intensity; in other words, waves which differ in length by several hundred meters do not vanish simultaneously.

This selective absorption does not seem to be limited to specific localities, appears mostly at sunset, lasts far into the night, but is seldom observed near noon.

At first I thought that the effect could be explained by altered conditions at the transmitter or receiving station, as, for example, thru alteration of antenna capacity because of the presence of fog, etc. But the persistency with which it occurred, and the fact that no amount of tuning at the receiving station remedied matters altho simultaneously other stations were receiving this wave perfectly, prevents the acceptance of an explanation on the grounds of atmospheric absorption, that is, such an explanation as is employed to clear up the daylight absorption at long ranges.

Clearly it is impossible that a wave of 3260 meters previously of satisfactory intensity can be absorbed completely at a distance of 350 miles while at the same time a wave of 3100 meters remains of full strength. And there is not much to be said in favor of the assumption that alterations of the refractive power of low-hanging cloud banks or of layers of clouds produce a bending of the wave trains which causes them to pass over the receiving station, while at the same time waves of only 5 per cent. differ-

Figure 9.

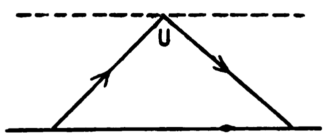


Figure 10.

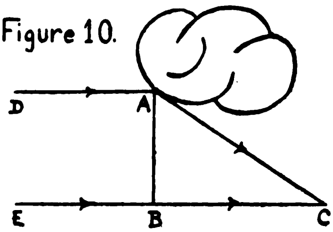


Figure 11.

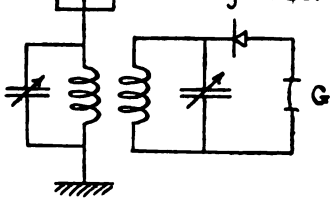


Figure 12

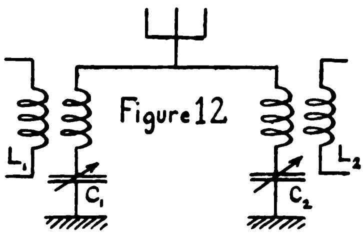


Figure 13.

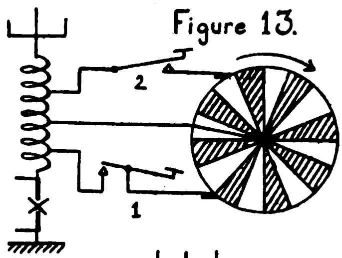


Figure 14.

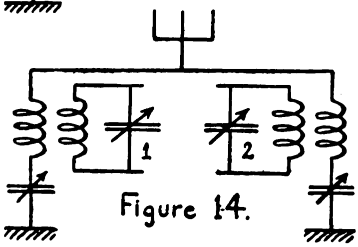


Figure 15.

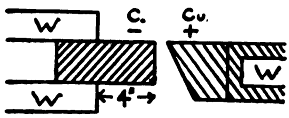
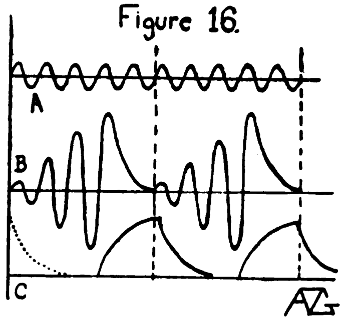


Figure 16.



ence in length are received as well, or even more strongly (as is frequently observed).

It is however possible, that under certain atmospheric conditions, which may be caused by clouds or masses of fog (which are found with great regularity at certain seasons on the Pacific coast), or by by partially ionized masses of air at greater heights. the energy of the upper part of the wave may be deflected or bent downward. Dr. Eccles at the Dundee meeting of the British Association pointed out that a bending of the wave as it travelled might be produced if the upper layers of air were even partly conducting. The appearance of the bending wave front as it travels from left to right is shown in Figure 8. Under such conditions there are acting at the receiving stations two trains of waves which have travelled over paths of unequal lengths or which have travelled with unequal velocities. Consequently there will be a phase displacement between them and interference at certain localities. These are the nodes at which total or partial extinction of the oscillations occurs.

The possibility of such an interference has already been mentioned by several authors in their speculations concerning the propagation of electric waves over the surface of the earth. For example, Professor Pierce, of Harvard University, states in his book: "Principles of Wireless Telegraphy," "The upper layers of the atmosphere which have been rendered conducting thru the action of sunlight, may act to a certain extent as reflectors of electric waves and thus limit their propagation over the surface of the earth; the transmission would then be superior in the day time, with the exception of the case where a possible interference occurred between the direct and reflected waves. This interference, if it exists, would strengthen waves of certain length and might annihilate waves of different length, so that this interference could be made of assistance by altering the wave length by an amount corresponding to half the period. No such effects however have been observed."

Dr. Pierce's conclusions regarding the superiority of daylight transmission are, as you know, contradicted by the experimental results. The ionization of the air at lower levels is able to counteract the influence of the reflection at the upper layers. On the other hand I believe that there is now ample evidence to concede the existence of such reflection as darkness approaches. In Figure 9, the conducting layer of air at U is shown and the path of the wave with its reflection at U is also shown.

How shall we account for the fact that the reflection effect was not observed till recently? In spark telegraphy two waves of nearly equal length were rarely used (with the exception of the case of those due to coupling of the open and closed oscillating circuits). Alterations in the wave length used in transmission are seldom attempted or else are of considerably greater magnitude than those used in our work with continuous oscillations, which latter therefore bring the desired effect into greater prominence. It would be interesting to observe whether similar observations have been recorded with sustained radiation in other climates, or whether these effects are limited to the particular atmospheric conditions and localities in which we have observed then.

Because of the great commercial demands on the stations up to the present time I have not been able to undertake a careful series of observations altering the transmitting wave by successive small steps in order to ascertain between what intervals of wave length these effects of interference or disappearance pass thru maxima and minima. Before an exact statement can be made theory and practice must work together for some time.

In Figure 10 is illustrated one set of conditions which would lead to the reflection and interference effects observed. Suppose we are working with two waves, λ_2, of length 3000 meters and λ_1 of 3150 meters. At A assume a reflecting surface (cloud bank or mass of ionized atmosphere). The distance BC is taken as 20 λ_1 which equals 21 λ_2. The distance AC is taken as 28.5 λ_1 which also equals 29.9λ_2. So that the difference of the paths for the two waves λ_1 and λ_2 is $28.5 - 20 = 8.5\,\lambda_1$ for the first wave, and $29.9 - 21 = 9.0\,\lambda_2$ for the second wave. The height AB is found to be 37.5 miles in this case. Its height is found to depend on its distance from the sending and receiving station provided the differences of paths of the two waves are assumed known. It will be seen that in this case the longer wave will arrive at C by two paths which bring the two portions of the wave to C in directly opposite phases. In consequence the longer wave will be partially or totally annulled at C. On the other hand, the shorter wave travels to C by two paths which bring the two portions of the wave to C in phase. They therefore reinforce each other and may appear with increased intensity. Other values for AB, BC, and AC are 27.7 miles, 10λ_1 or 10.5λ_2, and 18 λ_1 and 18.9 λ_2 respectively. Yet another set of values is 17 miles, 3 λ_1 or 3.15λ_2, and 10λ_1 and 10.5λ_2 respectively.

Figure 17

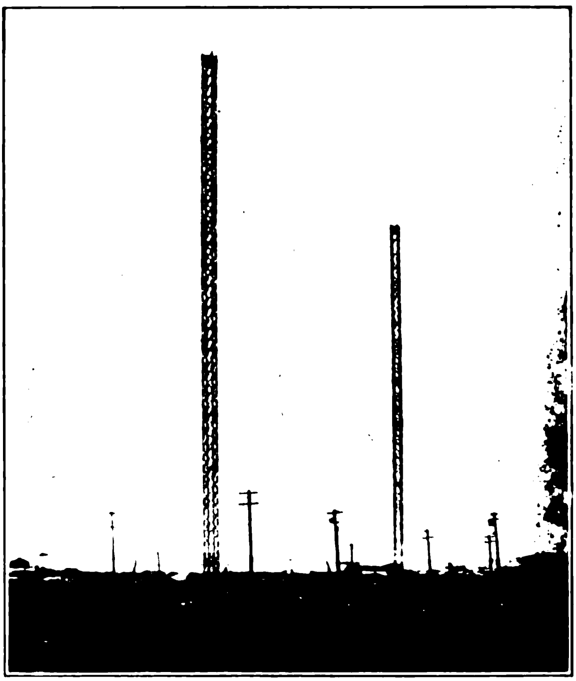


Figure 18

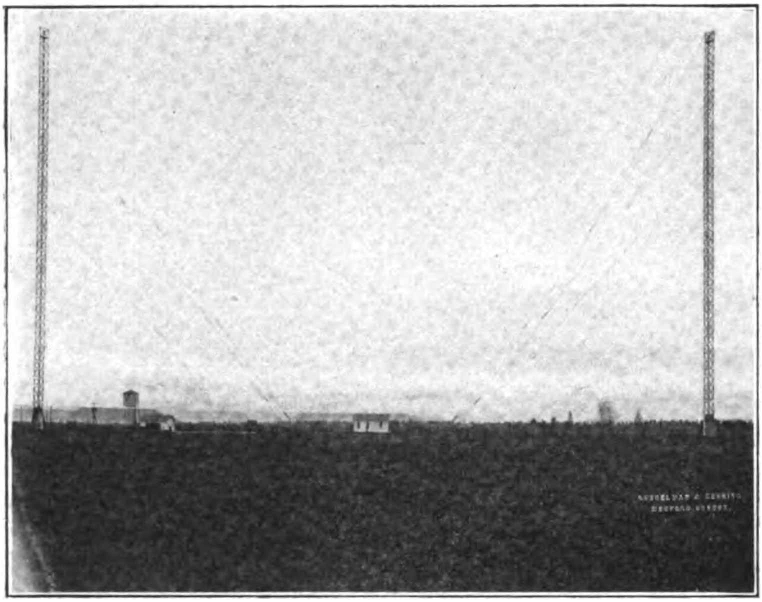


Figure 19

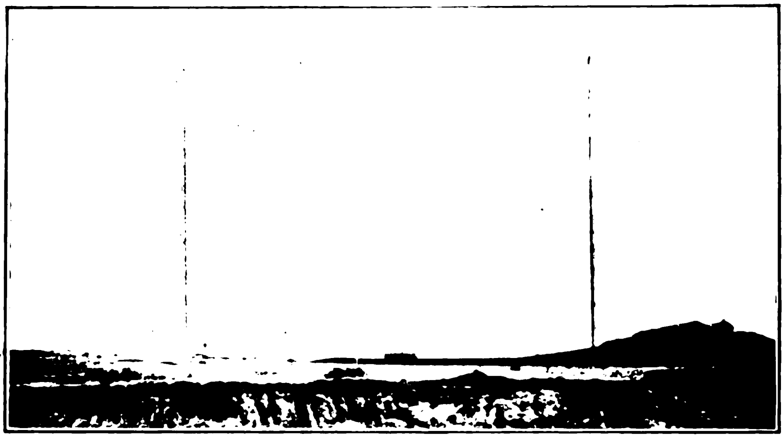


Figure 20

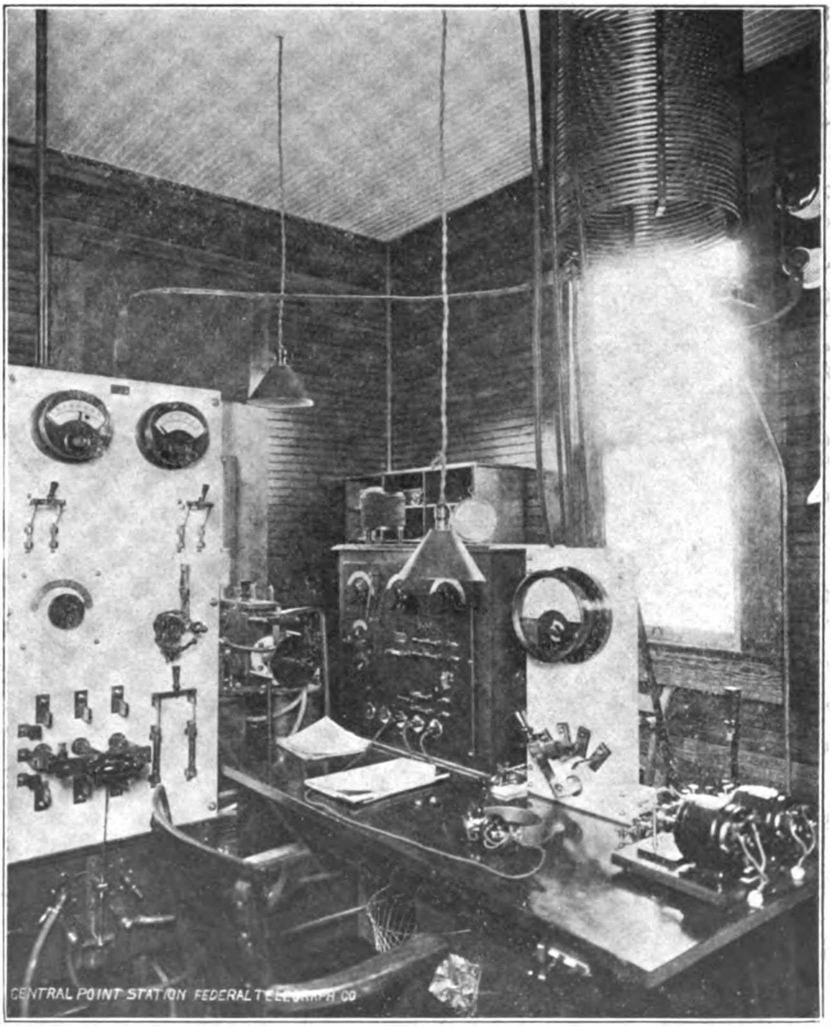


Figure 21

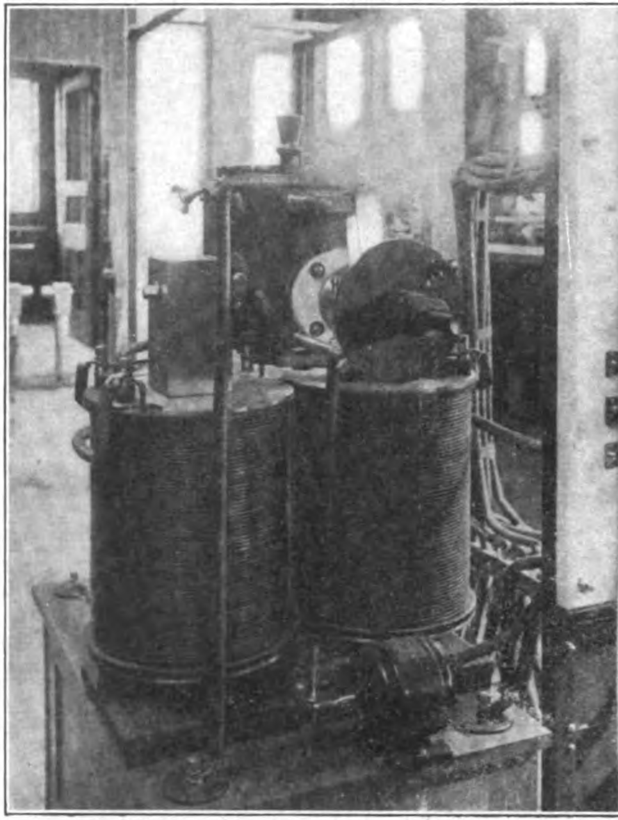


Figure 22

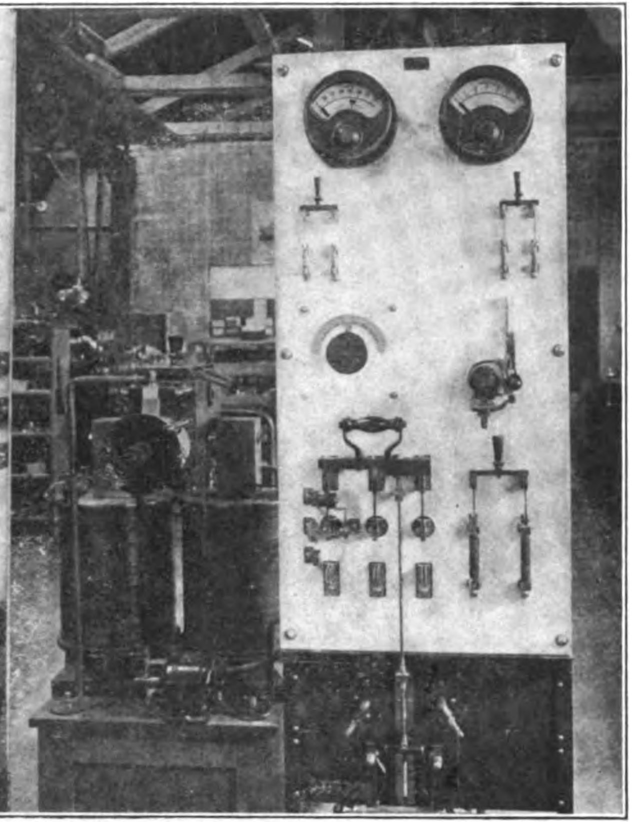


Figure 23

If the reflecting layer is half way between the stations, its height is 62 miles under the conditions here assumed. Five minutes is sometimes the interval during which the effect persists. For its disappearance the ionized layer need rise only one-half of one wave length. Almost never have both the waves faded at the same time. This shows that the reflecting stratum is at a great height. I believe that prolonged and tabulated observations will add considerably to our theoretical knowledge of this subject.

It is possible that the so-called "freak work" in wireless is due to this interference effect. It is impossible to say because we have had no simple way of changing the wave length suddenly in the quenched spark sets. But I believe that the extreme long distance work done by small sets must frequently be explained thus. Then too, it would account for the fact that the Marconi Transatlantic stations can operate sometimes with a few kilowatts and sometimes require 125 to 600 kilowatts.

And finally, to return to our commercial work, we now use a wave length of 5000 meters at our South San Francisco station. Thus we avoid interference with neighboring spark stations, altho properly tuned quenched sparks sets with a wave length differing 8 per cent. from our own do not interfere with us. It has been our aim to conduct our business with maximum certainty and minimum of interference, and we have succeeded so well in the first aim that we believe that any failure in the second is rather the fault of the other systems.

EDITORIAL NOTES.

Thru the kindness of the Federal Telegraph Company and Mr. Elwell a number of photographs illustrating the work of the company are here reproduced. Figure 17 is the antenna at San Diego. It is of the earlier double pole and spreader type. Figure 18 is the station at Portland, Oregon. The towers are square in cross section. A newer type of tower construction, namely the triangular cross-section type, is shown in Figure 19, the Central Point, Oregon, station. The Transpacific South San Francisco station is shown in Figure 20. In Figure 21 is shown the interior of the Central Point station. To the left is the 500 volt direct current control board with generator field rheostat, measuring

instruments, and breaker. Next to it can be seen the arc converter with its powerful field magnets, arrangements for artificial cooling, and front button which, when pressed, makes contact and starts the arc. To the left of the operator's table is seen the receiving set with variable inductances and capacities controlled from the front knobs, various switches for altering wave length range, etc., and the telephone jacks. Standing on the top of the receiving set is a specially wound coil which is employed when extra long waves are to be received. Next to the receiving set is the operator's key, and then the board where the wave length of the radio-frequency currents is controlled. The antenna hot wire meter is visible at the top of this board, and below it a rotary switch which enables the operator to rapidly change the wave length, which procedure, from the foregoing article, will be seen to be strictly necessary at times. To the extreme right of the operator's table is the motor-driven ticker for receiving. It is supplied in duplicate. At the top of the room is seen the antenna helix with the various taps leading to it. Near its bottom and to its right is seen the lightning switch.

The details of the transmitting apparatus are shown in Figures 22 and 23. Figure 22 shows the new Poulsen generator with special anode. There is a quick detachable bottom plug for cleaning the arc chamber when necessary. The massive field coils are shown. They are wound with heavy square cross section copper wire. Figure 23 shows the arc and its control board. Under the switch-board panel are shown the water valve lever which controls the flow of water thru the arc chamber jacket, and the receiving contact device. Both of these are operated by the large triple pole switch. This switch controls the flow of water, the flow of gas, the motor for rotating the carbon electrode of the arc, the power current, the radio-frequency circuit, the receiver circuit, and the motor-driven tickers.

The hypothesis suggested tentatively by Dr. de Forest relative to the opacity of the ether for certain wave lengths has, up to the present time, met with no substantiation. We are forced to regard it as highly improbable. The view that the interference effects are the results of the joint action of the direct and reflected waves, as also suggested by Dr. de Forest, is very probably correct, and should lead to valuable and extended researches on the most favorable locations of stations and wave lengths to be employed.

In order to render the action of the ticker somewhat more clear Figure 16 is inserted. It is intended to show the currents in the various circuits. Curve A gives the antenna current. Curve

B gives the current in the secondary tuned circuit. Curve C gives the condenser discharge current thru the telephone receiver. It will be noted how the resonance effects which are obtainable with sustained alternating current in the antenna are utilized fully. This ingenious receiving device is due to Prof. P. O. Pederson of Copenhagen.

The circuit arrangements for which these diagrams apply are somewhat different from those now employed, but embody the same principle.

Dr. de Forest has formally notified the Editor of the results of the tests at the Arlington station. The 30 Kilowatt arc was first tested on December 8th. Two way communication with South San Francisco, and also with Honolulu, was almost immediately established, altho at the time Honolulu was still in daylight! Owing to the greater height (600 feet) of the Arlington antenna, its signals are received with greater intensity than those of the latter station at Arlington. The energy used at Arlington was from 35 to 40 K. W.

ALFRED N. GOLDSMITH, PH.D.

DISCUSSION.

E. J. SIMON: I understand that using 35 kilowatts at the San Francisco station the antenna current is 40 amperes. What is the radiation resistance?

DR. DE FOREST: We have not measured it because it cannot be accomplished in the usual way, namely by the insertion of resistance in the antenna. The arc is directly in that circuit, and any change alters the conditions markedly.

DR. GOLDSMITH: It should be possible to accomplish the desired result thru the following means. Measure the arc voltage which is applied to the antenna (R. M. S. value of the alternating E. M. F.) by means of an electrostatic voltmeter. Then measure the effective inductance and capacity of the antenna at the desired wave length or frequency ω separately. Then if R is the radiation and ohmic resistance of the antenna, L and C its effective inductance and capacity, E and I the R. M. S. values of the voltage and amperage of the antenna, we have

$$R = \sqrt{\frac{E^2}{I^2} - \left(L\omega - \frac{1}{C\omega}\right)^2}.$$

E. J. SIMON: We may determine the damping by measuring the decrement by the Bjerknes method.

DR. GOLDSMITH: Before employing either of the above methods it would be well to calculate what effect the non-sinusoidal character of the arc current would have on the results.

E. J. SIMON: An artificial antenna or substitution method might be employed.

R. A. WEAGANT: In this case air condensers should be used in the artificial antenna.

E. J. SIMON: Does the ground extend beyond the horizontal projection of the antenna?

DR. DE FOREST: Yes; the extreme spread of the antenna is 400 feet, but the radius of the ground is 350 feet.

E. J. SIMON: The signals weaken in the morning. Is there any definite lag of the change of intensity of the signal as compared with the time of sunrise?

DR. DE FOREST: We have as yet made no such quantitative measurements.

R. A. WEAGANT: How loose is the coupling used in receiving?

DR. DE FOREST: Usually 10 to 15%. In cases of bad static it may be 5%.

E. J. SIMON: Do you use the longer wave because of its greater energy?

DR. DE FOREST: Yes, and to prevent interference, but the energy difference is small.

E. J. SIMON: What is the fundamental of the South San Francisco aerial?

DR. DE FOREST: About 2800 meters.

DR. GOLDSMITH: Will you describe the automatic sender, the optical printing receiver, and the diplex transmission and reception methods?

DR. DE FOREST: For high speed transmission we employ an automatic sender. For receiving at high speeds we use the Einthoven thread galvanometer, which consists of a fine thread of gold wire in an intense field of an electromagnet. It is placed in series with a rectifying detector and on receipt of incoming signals is slightly deflected. By suitable optical systems, a greatly enlarged shadow of the brilliantly illuminated wire is thrown on a moving strip of photographically sensitive paper, which is then

rapidly developed and fixed. From the wavy line on the strip of paper the message can be read. We have spent over $12,000 in investigating this method, and have imported the best instruments we could get in Denmark and Germany. But the entire method is impractical commercially and a flat failure. And it always will be. The Pederson high speed transmitting key is a device which is operated by punched tape such as is used in the Wheatstone sender. It is a somewhat complicated device which acts on the principles that small rotating rods, released by mechanical means, close light contacts and thereby permit heavier rotating contacts, which are always in readiness to operate, to add aerial inductance and thereby increase the wave length. The arrangement of circuits used with the Einthoven galvanometer is shown in Figure 11. The galvanometer is shown at G. The wire in it is 0.00005 of an inch in diameter. Our experience with it has been unsatisfactory. Static is sufficient to throw the spot of light completely off the moving paper strip, and we sometimes had to run the paper thru three times, and even three times three times, before a good record was secured. Even the possibility of sending more than 100 words per minute does not compensate for such disadvantages. A possible method of diplex is shown in Figure 12, where L_1 and L_2 are the primaries from which energy at different wave lengths is transferred to the antenna. Marconi tried something of the sort, but omitted the condensers C_1 and C_2, hence it is very doubtful whether the device operates as then shown. An extremely successful method of diplex operation is shown in Figure 13. It will be noticed that the contacts on the rotating sector wheel are so arranged that contact for key 2 is broken just as contact for key 1 is made. When neither key is depressed a medium wave of length 3200 meters, for example, will be sent. If key 1 is depressed the wave length rises to 3400 meters, and if key 2 is depressed a wave length of 3000 meters is emitted. If both keys are depressed, waves of length 3000 and 3400 are alternately sent out for short intervals of time. The arrangement at the receiving station is shown in Figure 14, where 1 and 2 are the two receiving circuits tuned to 3400 and 3000 meters respectively. This system has worked perfectly between Los Angeles and San Francisco. It is very practical, and arcing at the brushes has been largely overcome. I use 450 interruptions per second.

JOHN L. HOGAN, JR.: Have you any data as to the decrement of your receiving antenna circuit? You speak of extremely sharp resonance.

DR. DE FOREST: Stress of commercial business at the San Francisco station has prevented our making such measurements.

J. L. HOGAN, JR.: What is the comparative sensitiveness of the "Ticker" as compared with the solid rectifiers?

DR. DE FOREST: Qualitatively I should say that the ticker was about three times more sensitive. We get louder signals with the ticker signals from the arc station than we can get when we employ a "chopper" at the transmitting station to break up the outgoing wave train, and a rectifier at the receiving station. To give you an idea of the actual intensity of the signals, at Los Angeles the operators invariably use the typewriter while receiving.

J. L. HOGAN, JR.: Is the ticker ever run at interrupter frequencies as high as 1000 or 1200 per second?

DR. DE FOREST: No, the normal rate is about 200 per second. This gives a hissing note in the telephone receiver, a sound which is very characteristic, and easily read when one becomes accustomed to it.

J. L. HOGAN, JR.: You state that you use very loose couplings at the receiver, and that the tuning is much better than can be had with feebly damped oscillations of the type produced by quenched spark transmitters. Perhaps you will recollect that it has often been contended that if quite persistent waves were used one might secure all the resonance benefits of sustained wave transmission. If I recollect correctly, this was your own position formerly.

DR. DE FOREST: It was, but my recent work has forced me to change my opinion in that respect. We are able to secure tuning conditions that I would have considered impossible with the best quenched spark senders. I feel certain that with the sustained oscillations you can secure better tuning.

J. L. HOGAN, JR.: Have you made any measurements which would indicate that the attenuation term in the Austin-Cohen transmission equation should have a different value for sustained than for damped waves, or that there should be a factor included which varies with the transmitter decrement?

DR. DE FOREST: We have secured no data in that direction as yet. I expect to attack the reflection and interference problem more exhaustively first.

It may be of interest to those present to know that we have shipped a 30 kilowatt set to the Government station at Arlington, Virginia. For such sets we require an antenna capacity of 0.01 microfarad. This set should be installed within a few weeks. Personally I anticipate considerable absorption in the towers. They are too near together. By the first of the new year we will have a 60 kilowatt arc in operation. This type of arc brings with it new problems of cooling, etc. The general construction of our arcs is shown in Figure 15. Water cooling is accomplished by the water jackets and pipes at W. The diameter of the carbon in the 12 kilowatt arcs is 1 inch, and this may rise to 4 inches in the 60 kilowatt arcs.

MARCONI TRANSATLANTIC STATIONS.

At the request of President Marriott, Mr. Hallborg of the Marconi Company, who has lately returned from Europe, described the Transatlantic Marconi station at Clifden as follows:

The power used is 125 kilowatt, of which about 50 kilowatts is radiated from the aerial. Power is supplied by four 5000 volt direct current generators in series. These generators are of special type with slotted commutators and air blowing between the segments for cooling and prevention of destructive arcing. These machines charge a storage battery when it is desired to run the alternating current machinery which may be used to feed the high tension transformers. These last are of the American Transformer Company's manufacture with special means for avoiding high tension surges.

In receiving a static preventer is used wherein two balanced crystals are employed. Their current voltage characteristics are identical. The arrangement is similar to that employed by Eccles with the valves. The alternating current generators are each 500 kilowatt and 25 cycle.

The receiving aerial consists of 4 wires each 2000 feet longer than the sending antenna. The transmitting aerial is sometimes employed in a curious way to assist in tuning, by tuning it to the incoming wave and using the reradiated energy to assist the receiving aerial.

At this point Dr. de Forest remarked that he had noticed that large aerials tuned to the incoming wave assisted smaller ones in their vicinity thru the reradiated energy.

Volume I Part 2

PROCEEDINGS
OF THE
INSTITUTE OF RADIO ENGINEERS

CONTENTS:

EDITED BY
ALFRED N. GOLDSMITH, Ph.D.

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RADIO OPERATION BY STEAMSHIP COMPANIES.*

By Robert H. Marriott

(*Vice-President and Past-President of the Institute*)

I believe that the INSTITUTE will show marked advancement during the year 1913. Papers are issued in the PROCEEDINGS, reports of the Standardization Committee are in preparation, and other Committees are actively engaged in valuable work. It is felt that the INSTITUTE OF RADIO ENGINEERS presents some features which are of use to every person engaged in the radio art.

There is a twofold reason why the membership of the INSTITUTE should and will increase. We must consider not only the benefit to the members resulting from the activity of the INSTITUTE but also the benefit to the art of radio communication, to the users of radio apparatus, and to the general public. Almost every portion of the present radio equipment and business routine will bear improvement. (Some parts are badly in need of it). The INSTITUTE should be a guide to the best possible radio service. We desire instantaneous communication in cases of distress, and adequate, rapid, and accurate communication at all times. The membership of the INSTITUTE can be a potent factor in the attaining of this state of affairs.

Misrepresentation concerning radio apparatus and radio companies has been, and unfortunately still is, a damper on the advancement of the radio science and art. One of the most commonly prevalent methods has been to provide an able press agent with a company owned or controlled publication, and with the privilege of inserting such statements as may suit his fancy in acquiescent newspapers. Many mysterious and hero-worshipping exaggerations have thus found their way into the press. Thus the public has been at times woefully misinformed. Such a misleading policy is directly opposed to the spirit of the INSTITUTE. What is wanted

* Lecture delivered before THE INSTITUTE OF RADIO ENGINEERS, January 8th, 1913, at Fayerweather Hall, Columbia University.

about radio apparatus and engineers is the simple truth.

This address was originally planned as a resumé of the progress in radio art during 1912, including that of our members, but one topic has become the main subject of the paper to the exclusion of the resumé. However, I wish to mention before proceeding with the main subject, that Dr. Lee de Forest has given us an excellent account of some notable long distance work and observations with an interesting theory which may help to explain and overcome radio absorption. This absorption of signals is one of our worst enemies, and we feel grateful to Dr. de Forest for the work he has done in attempting to find how it is brought about.

It was while writing of the work of Messrs. Davis and Parkhurst of the United Fruit Company that the main subject of this address was brought out. We frequently hear the statement that the United Fruit Company has practically the best radio service. If this is true, it may indicate that the steamship companies would obtain better radio service if they bought their apparatus outright and hired their own operators and engineers. Whether such a course is the best one is certainly a topic worthy of discussion. For such a discussion should assist in bringing about an improvement in radio communication whether the operating is done by the steamship companies or by general operating companies.

There are at least eighteen members of this INSTITUTE who are capable of designing and constructing far better apparatus than is commonly found on steamships to-day, and there are at least four companies in the United States that sell such apparatus.

In favor of the method of obtaining apparatus through competitive bids, the fact may be stated that the United States Army and Navy get superior apparatus by specifying to a certain extent what is wanted and then calling for bids. Their equipment is therefore obtained from more than one company.

Radio communication is valuable to the public in general. It is particularly valuable to the ocean-going public, steamship companies, marine underwriters, newspapers, shippers, armies, navies and weather bureaus. For all this service the public probably pays in the end, but the most apparent (or possibly it would be better to say the most painful) payment is that made by the steamship companies. They feel the

financial burden most directly. The best radio service can be attained only when each person concerned sees clearly that he is receiving a just return for his investment. If, as may be the case, the steamship companies or any of the other users of radio service are not getting just returns in the way of apparatus, service or financial reimbursements, they should be shown how to get them.

The sinking of the Titanic brought out clearly some of the strong and weak points of the radio service at that time. Many of the weak points have not as yet been remedied. There is apparatus on many vessels, which is a disgrace to radio-communication. Much of it was out of date four to eight years ago. A possible explanation of this fact is found in the following considerations.

The government departments usually get the best available apparatus because they employ experts who understand the science and art. So that high class apparatus is usually specified and bought from the manufacturer who provides the desired apparatus at the most reasonable cost. Apparently the steamship companies know very little about radio apparatus. Some of their vessels are equipped with apparatus which would not have been accepted by the navy ten years ago.

In suggesting radio operation by the steamship companies, we should consider the matter of profit or greater profit.

Paying and boarding the operator is probably the main expense in all cases. But there should be more or less work which could be done by the operator while listening for calls. Let us assume that the variation of the receiving tune required for picking up signals be accomplished by a spring or electric motor. This is feasible, and the work may be done much more thoroly than the average operator does it by hand. Freeing the operator from this manual labor would leave him free to do clerical or similar work. It is said that some of the Pacific steamship companies now have operator freight clerks who earn good salaries.

Probably an investigation on the part of the steamship companies as to the requirements of the communication part of their business would show them new and profitable ways in which the radio service might be employed, and other functions for the operator. It may be mentioned that if the operators were shown how to educate the public in the valuable

ways in which radio service may be used and were given a bonus on the business handled, undoubtedly the receipts would be materially increased. The handling of the business should involve no difficulties, for a steamship company has sufficient office force to handle the operators, and the salary and message accounts.

As to the maintenance of the steamship-owned apparatus, properly designed apparatus in the hands of first class operators should require very little repair. Such special repairs as would be needed occasionally might be provided for in the contract with the manufacturer.

At present, the radio operator on a steamship is a somewhat undefined position. He is paid by an operating company and carries on the business of that company; he signs with the steamship company; he takes his orders from the operating company; he is supposedly under the captain; he has charge of important work; and finally, he gets little, if any, more pay than an ordinary sailor. This confusing state of affairs should cease to exist if the steamship companies operated their own radio equipment.

Formerly more or less specious arguments were presented by the operating companies to prevent the steamship companies from purchasing and using radio apparatus. The operating companies claimed that they had a patent monopoly, and that their reason for merely renting apparatus was that it was in their power to prevent the use of apparatus not supplied by them. The fact that other companies continued to make and use such apparatus and that the government continued to obtain all the apparatus it desired without renting it showed that this claim was at best a weak one. A later claim made by the operating companies was that they controlled all the stations in their field, and that in consequence stations of any other system in that field would have nobody to work them. But laws have been passed which compel the exchange of messages regardless of the system used. Even if the operating companies closed their shore stations, there would still remain the naval stations. And it is quite possible that the newspapers or wire telegraph companies would erect stations as means for obtaining news or as feeders to the land lines. And finally, it was stated that radio operators were difficult to train and to hire. They probably are not very

anxious for employment when they are offered only thirty or forty dollars a month.

Let us contrast the conditions now existing with those which we might expect to exist if steamship operation of radio communication were generally adopted. Suppose at present the steamship companies are paying between one hundred and one hundred and fifty dollars per month for two unprofitably occupied operators, an inferior equipment, and inferior service. If now the steamship company were to buy a first class equipment (for which it would pay, say, three thousand five hundred dollars), and were to give two first class operators profitable work which would reimburse the company for their salaries and accomodations, the company should insure for itself and its passengers prompt and correct radio service under ordinary and distress conditions. It could secure a share of the message tolls received from the passengers, dividing the remainder of these tolls between the shore stations and the operators. It would place the operators in a definite relation to the remaining of the ship's crew. And it should be protected against patent suits by the manufacturer of the radio apparatus.

It seems to me that the latter arrangement is far more satisfactory and profitable. With the salaries of the operators eliminated from the expenses to be charged to the radio service, the former rental of one hundred to one hundred and fifty dollars per month certainly should be more than sufficient to cover interest and depreciation on the thirty-five hundred-dollar investment.

Probably twenty per cent of the members of the INSTITUTE are connected with operating companies, and five per cent with manufacturing companies, while the remainder have more or less impartial relations with both. So that I may hope for a fair and thorough discussion of these suggestions.

I wish to express my gratitude for the honor which, for four years, has been conferred on me: the presidency of the Wireless Institute and the presidency of THE INSTITUTE OF RADIO ENGINEERS.

It gives me great pleasure to pass the office of president of THE INSTITUTE OF RADIO ENGINEERS to a man whom I have known and appreciated for eleven years, a man famous throughout the radio world, Mr. Greenleaf W. Pickard.

DISCUSSION.

PHILIP FARNSWORTH: I shall undertake to start the discussion of Mr. Marriott's very able paper. The paper was brim full of timely suggestions. But I think that some of us may reach different conclusions from those presented. Concerning the methods of commercial management of radio communication, the interesting question is raised whether it is best to have a single operating company or to split up the operating company into separate smaller and competing companies. In my judgment, the natural laws of business will automatically regulate this.

I shall endeavor to consider the matter entirely independently of the question of patents. Independently of the patent matter, it is a question whether it is not better to have a single operating company. It is really a question of good service, rather than of patents or of monopoly. The case may be considered to be similar to that of the Telephone Company. In that case, exclusive operation by a single company seems the best policy. Even some of the objectionable features of operation by a single radio company are not inherent faults of the single-company plan, and are remediable by the operation of natural laws of trade. And by placing the operation in the hands of one company a chaotic state of affairs is avoided which otherwise might occur.

The case of the radio work of the Government can hardly be fairly adduced as an argument for radio operation by the separate steamship companies themselves. The Government work is substantially under unitary control, and this tends to promote good service. If the individual steamship companies separately operated, that might tend the other way. If the policy of a single operating company is continued, it is obvious that such a company should co-operate with the Government and endeavor to provide a service at least as good as the Government's.

The work of the radio operator has always seemed to me rather responsible and difficult. I must confess that I cannot understand how it would be advisable to burden him with

other duties as a steamship freight clerk. His close and continued attention to his work seems essential, but of course, it is possible that additional work might be permitted, under two-operator requirement.

ROBERT H. MARRIOTT.: The wire telephone is limited to available wire space, while the medium of radio communication, the ether, is apparently unlimited. For this and other reasons I consider the Telephone Company and general radio operation companies to be quite different types of organizations.

To protect the public, certain standards of apparatus and operation are required by law, and the steamship company is held liable in case of failure to obey the law. Therefore, it seems to me that the control of the apparatus and operators might better be in the hands of the steamship company, it being the responsible body.

Not only the case of the United States Government, but also that of the United Fruit Company indicates that it is thru open competition that the better apparatus is obtained.

As regards the time of the radio operator: in many cases he does not do much work. On the small boats, he probably averages under present conditions one message and three distance reports each day, so that, at the rate of twenty words per minute, it cannot take long for him to complete the actual manual labor. At present a large number of operators become tired and dissatisfied, because they have nothing to do.

PHILIP FARNSWORTH: I have the impression that the purpose of that clause in the law requiring two operators was that one would have the opportunity to sleep while the other worked; that is, one operator at least would be listening all the time, night and day. It seems to me that the duties of freight clerk might be inconsistent with those which the spirit of the law demands from the radio operator, but I confess I do not know as much about the matter as Mr. Marriott.

ROBERT H. MARRIOTT: The value of the services of a radio operator as an insurance against the loss of life and property is underestimated and not appreciated. The problem, as I see it, is to give the operator work which will bring him an income which is in proportion to the amount he is worth. The steamship company will increase his income only for a tangible reason.

As to the demands on his time by listening in, there is nothing to prevent him from wearing the telephone receivers while doing his freight clerk work, the tuning being done automatically by a spring or electric motor. Experience has shown that he will recognize his call or a distress signal even when deeply engrossed in other work.

CHARLES A. LE QUESNE, JR.: The receiving set might be normally adjusted to the distress tune, and only adjusted further when there was special need for it. In regard to radio operators doing other things than receiving messages, on the Pacific coast there are a number of operators who also act as assistant pursers. The operators do not like the double duties, however. Maybe this is because they get no increase in salary.

EDWARD GAGE: From my experience, I should not think that an operator could satisfactorily fill another position as well.

CHARLES A. LE QUESNE, JR.: In the case of automatic tuning, one might pass the wave length on which one was being called just during the space between two dots or dashes, and thus miss the signal.

ROBERT H. MARRIOTT: The tuning can be accomplished quite as slowly mechanically as by hand.

FRANK FAY: The operator can always hear things of interest to him even when he is not paying particular attention to them. In ordinary telegraphy, an operator recognizes his own call, no matter how inattentive he is.

EDWARD GAGE: The method proposed might suffice for isolated stations, but not for stations handling much business.

ROBERT H. MARRIOTT: The method of automatic tuning is primarily suggested for stations which do not get the opportunity to handle much radio business. If the station handles much business, the operator can earn a fair salary without doing other work.

LLOYD ESPENSCHIED: There appears to be two sides to the question, one of economic efficiency and the other of justice. Undoubtedly greater efficiency can be realized under one management, and, other things being equal, a single organization would therefore be the best. The case of the telephone company may be cited.

In radio work a tendency is manifest toward the concentration of power by patent monopoly. If a patent monopoly were realized, the government would be in the position of furnishing the mainstay (patents) for the trust and at the same time furnishing the market for its product by means of laws compelling the use of wireless. This would work an injustice to the wireless customer. It is only where monopoly is inherently necessary or is obtained and held through superiority of service that it is justified.

ROBERT H. MARRIOTT: It is unfortunate if a patent prevents the accomplishing of some object efficiently. But from the large number of makers of radio apparatus, one would conclude that after all the patents are weak.

Another advantage of superior apparatus would be that the operator would get louder signals and less interference from other stations and from the so-called "static."

LESTER ISRAEL: The telephone company is more efficient as a single concern, because in that case the most important part of the equipment is in the wire lines. But in the case of the radio station there is no cost for interconnection. The advantage of combination in the case of the telephone is that the needless duplication of long and expensive wire lines is avoided. Radio service differs so radically in this respect that no parallel conclusion can be drawn.

FRANK FAY: In the case of the telegraph companies, forty-three per cent. of the capitalization is in overhead lines, which, therefore, is not the main item of expense.

ALFRED N. GOLDSMITH: I should value the opinion of the members present as to the propriety of granting patents which constitute potential bases of monopoly in a developing art, such as that of radio-communication.

LLOYD ESPENSCHIED: The granting of patents in the form of *MONOPOLIES*, as in the present practise, is, I believe, morally and even economically wrong. There has been proposed a system which possesses merit — that of granting a bonus to investors. The matter of finding a better patent system is, of course, a subject ill adapted to hasty consideration.

JOHN L. HOGAN, JR.: The question is apparently one of good and bad trusts, and so broad a topic we cannot hope to discuss thoroly here.

To come back to the case of the United Fruit Company: This corporation is one having special powers, as it does a large telegraphic business from ship to ship and between its shore stations. It is able to maintain a system which cannot be maintained by a smaller company. A steamship company of the size of the Old Dominion Line, for example, would not be in the position to maintain such an operating and bookkeeping system. It would be unprofitable. What the steamship companies desire is good apparatus and service.

We have had during the evening various hints that misrepresentation of apparatus is practised occasionally. If the steamship companies were to purchase their apparatus and attempt to operate it themselves, they would be misled by the same rosy claims. Rather improve the operating companies and thus remove the objections against them.

PHILIP FARNSWORTH: I do not intend to say that radio "control" should be in any corporation. "Control," or perhaps a better term is "supervision," is very properly in the Government. But, as in the case of the telephone system, is it not a fact that the best service accompanies *operation* by a single company, because of the resulting economies in and efficiency of both the manufacture of apparatus and the operation of the telegraph service? Be assurred that in the case of persistent failure to supply suitable apparatus and good service, that very failure would have its natural result, as would also any attempt to enforce an unnatural or unfair monopoly.

But is there anything inconsistent between a single company and the best apparatus and service? And is there any reason why the single company cannot co-operate with both the Government and the steamship companies to secure the best apparatus and service for both the Government and the steamship companies? Is there any reason to suppose that a single company is not in the best position to effectuate improvements and standardization for apparatus and service common to both the Government service and that of the steamship companies?

It surely is not the natural function of either the steamship companies or the Government to develop and improve radio apparatus and service. And is not a single company in the best position to take and maintain the lead in the improve-

ment of apparatus and service, for both Government and steamships? It would seem to be the best policy for a single company to provide even better apparatus and service than the law requires, and it is believed that both the Government and the steamship companies, stimulated by public opinion, would cheerfully pay adequately for such service. I heartily agree with Mr. Marriott's statements concerning the power of the will of the public. And to an enlightened management, the possibilities of successful competition as the effect of poor service supplied is a sufficient inducement to provide everything of the very best character.

It is true that a steamship company is a public service concern, and from this some persons might argue that it is logical that the public service of operating a radio telegraph company might be properly executed by the steamship companies. But each of the many steamship companies has its own management independently of the others; the operation of a radio service is not a natural function of a steamship company; and the radio service, including both the design and production of apparatus and its operation in the public service, requires specialists and a competent general management such as only a radio company can provide satisfactorily.

It is intimated that the service of some of the radio companies is not all that it should be. But even if that be true at present, the radio service is yet youthful and I am confident that the managements are doing everything in their power to make improvements. Even if the Government's service at present is better than the service on the merchant marine, we ought to remember that the Government has been paying more for its apparatus and service.

As to patent monopolies, I would have you consider the interests of the inventor and patentee. The object of the grant of a patent is to promote and develop an art. It offers an inducement to inventors. What we all want is to have the art developed and better servive provided. The term of a patent is only seventeen years, and in return for the exclusive use of the invention during that time, the inventor discloses it to the public by way of the patent, so that everyone may use it after the seventeen years are up. The term is really a very short one, in view of the fact that usually no profits are realized until the patent is several years old. Of course, if a large com-

pany exists, which can pay the inventor a fair price and put the invention into use, that is advantageous to everybody. But the term of seventeen years is none too long in any case.

Of course, the broader a patent is, the harder it is to devise non-infringements, but this also helps the art by compelling more new inventions. The fact is that the real inventor of an improvement to-day stands little enough chance of enforcing his limited monopoly and obtaining adequate compensation for his contribution to the art. But it may be that a law can be devised which will improve these conditions while also preventing abuse by corporations of the privileges of patents.

There seems to be no difficulty in the patent situation if one radio telegraph company were in control of the field. If inventors outside the company produce useful improvements, the company must buy such improvements or compete with them. The more strongly the patent laws support the inventor, the greater is the price the company has to pay and the less its chance of successful piracy. On the other hand, if the company's employees produce the improvements, the company is entitled to its economic reward in the form of a monopoly lasting for a very limited term.

In short, let us, in considering the status of a patent and possibility of a single radio company, follow the "rule of reason."

LLOYD ESPENSCHIED: The inventor can be given sufficient reward without being given a monopoly. There is a movement on foot to secure a revision of the patent laws in the direction of broadening the circle of those who may manufacture under a patent, even without the inventor's consent.

Apropos of the discussion regarding patents which has arisen, I would suggest that the subject be more actively pursued by the INSTITUTE, especially in view of the agitation now being carried on by engineering and scientific bodies for a thorough revision of our patent system.

THE PRESIDENTIAL INAUGURAL ADDRESS: ENGINEERING ETHICS.

By Greenleaf Whittier Pickard
(*President of the Institute*)

Members of the INSTITUTE OF RADIO ENGINEERS:

I sincerely thank you for the confidence you have shown in me by your votes. While our membership represents many still opposing interests in the commercial field, I am certain that during the coming year we will work harmoniously together for the advancement of the art of radio-communication.

Fortunately our Constitution does not require a *formal* address of the incoming President. After my predecessor's able address, I fear that any extended talk on my part would be an anti-climax. I believe, however, that there are several important lines along which our energies for the coming year may be well directed, and of these I will speak briefly.

The work of our Committee on Standardization is admittedly of first importance. Our art has grown so rapidly that many of us have, perforce, made our own and sadly variant technical vocabularies. To progress, we must standardize; we must all speak and understand the same language. Much work has already been done, and well done, by this committee, and, I can safely say, much remains to be done during the present year. Standardization, in such a branch of the electrical art as ours, may never be complete. Rather, it must be a living, growing structure, added to and revised to keep pace with the changes and development of the art.

Our membership should be increased. The influence, we as a body may exert, depends both on our size, and the character of our members. I believe that there are many active workers in this field, at least qualified for associate membership, who would join us if they appreciated the value of association with our INSTITUTE. And I am certain that there are a number of men, both in this country and abroad, eligible for full membership, who would make useful, active members of this INSTITUTE. We need these men, and they will join

us, if our work and our aims are made known to them. Our standing Committee on Publicity is our present link with the outside public and technical world. I am not sure but that a special Committee on Increase of Membership might well supplement, in this particular direction, the work of the Publicity Committee.

This mention of our Committee on Publicity and my predecessor's discussion of misrepresentation of apparatus and achievements reminde me of our connection with and our duty to the public. Men in any technical pursuit are apt to forget, in the absorption of their work, how intimately they are linked with the general public. It may be somewhat early to even mention a code of ethics for our profession, and I certainly do not wish to suggest the appointment of a committee for this purpose. Yet, perhaps, we are in greater need of such a code than our brethren in any other branch of engineering. In the past, and even at the present time, much of the commercial development of this art has been assisted financially by the public. We owe a duty to this public, and our individual part therein is perhaps best expressed by a quotation from a report presented by the Committee on a Code of Ethics at the 24th Annual Convention of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, in 1907.

"In both his professional and his business relations the electrical engineer should follow strictly the same ethical principles that are recognized in the social relations of everyday life. He should consider himself personally responsible for the character of the enterprises with which he is associated professionally.

"Before he enters into professional relations, it is his duty to satisfy himself that the enterprises with which he connects himself are of a legitimate character. If, after becoming associated, he finds them to be of a questionable nature he should sever his connection as soon as possible. It should not be considered an excuse that his connection extends only to legitimate engineering work.

"By permitting the use of his name in any enterprise or exploitation he becomes morally responsible for its character. He should therefore not allow the use of his name in connection with anything upon which he is not qualified by training and experience to exercise competent judgment.

"He should endeavor to assist the public to a fair and correct general understanding of electrical matters, spread the general knowledge of electrical engineering, and discourage wrong or exaggerated statements on engineering subjects published in the press or otherwise, especially if these statements are made for the purpose of, or may lead to, inducing the public to participating in unworthy schemes."

Many feel that ethical codes are best followed when unwritten. I believe, however, that something may often be gained by the repetition of even truisms, and I am sure that it is not Utopian to consider the above quotation as applying strictly to ourselves.

I cannot close without a word of appreciation for the work of our past President, Mr. Robert H. Marriott. He has given unsparingly of his time and energy in the formation, building up and directing the activities of this INSTITUTE. He has initiated, and guided to a strong development many important lines of work. I am reconciled to my present office only by your wise action in electing him our Vice-President. If we can carry forward the work he has so ably started, in such a manner as will insure its soundness, I shall feel my administration a success.

THE EFFECTS OF DISTRIBUTED CAPACITY OF COILS USED IN RADIO-TELEGRAPHIC CIRCUITS.

By Frederick A. Kolster
(*United States Bureau of Standards*)

During the past eight or ten years much more attention has apparently been given to the development of the transmitting apparatus in radio-telegraphy than to the receiving apparatus.

Consequently the same sort of apparatus used five years ago or more to receive highly damped multi-frequency waves is still in use to receive the more persistent waves of single frequency which result from the improved transmitters of to-day.

It is, of course, apparent that the more nearly undamped are the transmitted waves, the more care must be taken in the design of the receiving apparatus.

Among the many things to consider in the design of circuits in which persistent radio frequency currents exist, are the effects of distributed capacity in the coils of the circuit.

It is the purpose of this paper to give the results of some preliminary experiments which were conducted with the view of determining how important are the effects of the distributed capacity of coils used in radio frequency circuits. At first thought, these effects would seem to be of minor importance, and this is generally true if proper precautions are taken in the design of the circuits and the construction of the coils.

In much of the apparatus in practical use, however, those precautions have apparently not been taken, with the result that peculiar phenomena are often observed. In laboratory apparatus for calibration and measuring purposes consideration of distributed capacity effects is of extreme importance.

It is not unusual in practise to find that coils used in wave meters and receiving apparatus have distinct natural periods or frequencies in the range of frequencies for which the circuit may be adjusted.

If the inductance of such a coil is measured at various frequencies, it will be found that this inductance apparently changes with the frequency as shown by the curve of Figure 1. The crosses on the curve indicate experimentally observed values. The natural wave length of the coil tested is about 260 meters and its inductance approximately 1.5 milli-henrys when measured at very low frequencies.

If it is assumed that a coil having distributed capacity may be, for all practical purposes, artificially represented by a loop circuit containing inductance and capacity in parallel as shown in the diagram of Figure 1, then we may write for the apparent inductance of the coil, if resistance is neglected,

$$L^1 = \frac{L}{1 - L\,C^1\,\omega^2}$$

where L is the true inductance of the coil, C its effective capacity, and ω equals 2π times the frequency.

If this assumption is good, it should be possible to determine the values of L and C of an equivalent loop circuit such as to make its apparent inductance equal to that of the coil under test for the range of wave lengths desired.

Considering now the curve in Figure 1, we may write for any two wave length or their corresponding values of ω,

$$L_1^1 = \frac{L}{1 - L\,C\,\omega_1^2} \quad \text{and} \quad L_2^1 = \frac{L}{1 - L\,C\,\omega_2^2}$$

By elimination we get

$$L = \frac{L_1^1\ L_2^1\ (\omega_1^2 - \omega_2^2)}{L_1^1\,\omega_1^2 - L_2^1\,\omega_2^2}$$

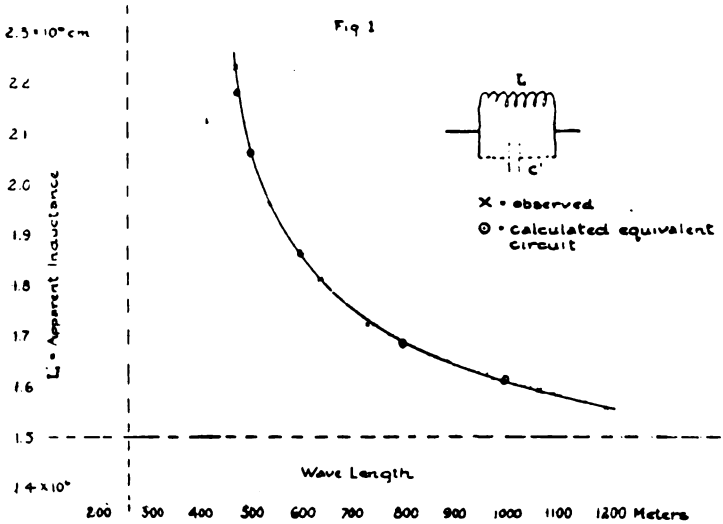
or in terms of wave lengths, since $\omega = \frac{2\pi v}{\lambda}$

$$C = \frac{L_1^1\,L_2^1\ (\lambda_2^2 - \lambda_1^2)}{L_1^1\,\lambda_2^2 - L_2^1\,\lambda_1^2}$$

Averaging the results obtained by taking several pairs of points on the curve in Figure 1, a value of 1.50 millihenrys is obtained for the true inductance of the coil measured.

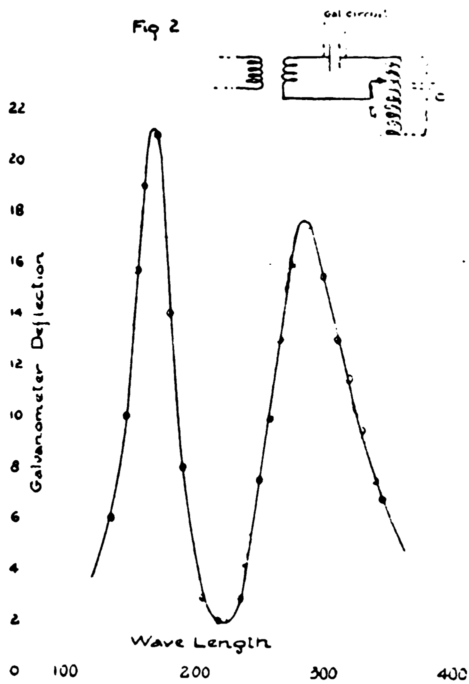
The value of the effective capacity of the coil may be

Fig 1



2.3 × 10⁶ cm
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4 × 10⁶
Lᵢ = Apparent Inductance
L
C'
X = observed
⊙ = calculated equivalent circuit
Wave Length
200
300
400
500
600
700
800
900
1000
1100
1200 Meters

Fig 2



Gal circuit
C
22
20
18
16
14
12
10
8
6
4
2
0
Galvanometer Deflection
Wave Length
100
200
300
400

expressed as

$$C = \frac{1 - \frac{L}{L^1}}{L\,\omega^2}$$

or, in terms of the wave lengths as

$$C = \frac{\lambda^2}{4\,\pi^2\,v^2}\left(\frac{1}{L} - \frac{1}{L^1}\right)$$

Averaging the results obtained for various wave lengths we get for this capacity, 0.000013 micro-farads.

The coil in question may, therefore, be represented by an equivalent loop circuit having a condenser of 0.000013 micro-farad in parallel with a coil of 1.50 millihenry. The circles on the curve in Figure 1 indicate the calculated apparent inductance of this equivalent circuit for the ranges of wave lengths indicated, showing that the assumption made is good for all practical purposes.

The diagram shown in Figure 2 represents a common form of circuit used in receiving apparatus and in some forms of wave meters. The loading coil L of considerable inductance and distributed capacity is divided into sections one or more of which may be connected in circuit to allow adjustment for various ranges of wave lengths. The imaginary condenser in parallel with this coil represents the effective capacity of the coil. For short wave lengths only part of the coil is in circuit, the unused sections being, however, inductively related to the part in circuit. It will be seen that this arrangement is really a case of two closely coupled circuits which should undoubtedly respond to two distinct frequencies or wave lengths. This fact is shown to be true by the experimentally obtained curve in Figure 2.

A brief theoretical consideration of a circuit of two degrees of freedom as shown in Figure 2 is of interest. This circuit may be diagrammatically represented by the circuit in Figure 3.

The reactance of the loop circuit 1 1^1 c^1, if resistance be neglected, may be written,

$$X = \frac{l\omega\,(l^1\,C^1\,\omega^2 - 1)}{(l^1 + l)\,C^1\,\omega^2 - 1}$$

The curve (a) in Figure 3 shows the variation of the reactance of such a loop circuit for various values of ω. Curve

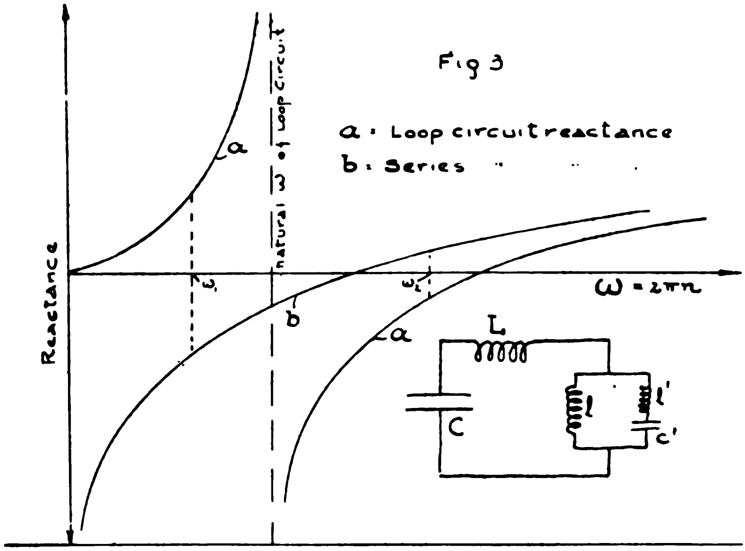


Fig 3
a : Loop circuit reactance
b : Series " "
Reactance
natural 3 of Loop Circuit
a
b
ω_1
ω_2
$\omega = 2\pi n$
L
C
l
l'
c'

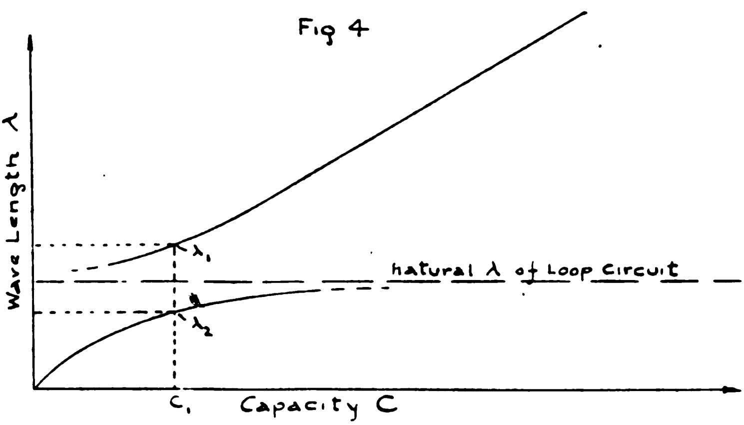


Fig 4
Wave Length λ
λ_1
λ_2
natural λ of Loop Circuit
C_1
Capacity C

(b) gives the reactance of the series circuit L,C for various values of ω.

The total reactance of the system for various values of ω is therefore the sum of these two curves, and it is seen that zero reactance is obtained for two values of ω, showing that for any particular setting of the condenser C, the system will respond to two distinct wave lengths.

For various settings of the condenser C, a calibration curve as shown in Figure 4 is obtained. Such cases as this actually occur in practice, the cause being entirely due to the effects of distributed capacity in coils.

The radio-frequency resistance of coils with appreciable distributed capacity is found in practice to be higher for some frequencies than that calculated from the well-known formulae. This may be at least partly explained if we again assume that such coils may be represented by equivalent loop circuits.

A loop circuit having an inductance L with calculated radio-frequency resistance R, in parallel with a condenser C as shown in the diagram of Figure 7 will have an apparent resistance

$$R^1 = \frac{R}{R^2 C^2 \omega^2 + (L C \omega^2 - 1)^2}$$

Curve (a) in Figure 7 gives the calculated radio-frequency resistance of a particular coil for various wave lengths. Curve (b) gives the apparent radio frequency resistance of this coil for this range of wave lengths, taking into consideration the distributed capacity and treating it as a loop circuit.

Distributed capacity effects in the coils of the so-called untuned or aperiodic detector circuits are in many cases very striking, the result being that the circuit is not at all aperiodic but responds much more violently at a particular frequency depending upon the natural period of the coil.

The so-called untuned detector circuit is shown in the diagram of Figure 5. The curve in this figure shows experimentally observed galvanometer deflections when the circuit is excited at various wave lengths. A comparatively sharp resonance curve is obtained showing that the circuit is distinctively not aperiodic.

An extremely interesting and ingenious method for determining the value of the effective capacity of a coil is described

Fig 7

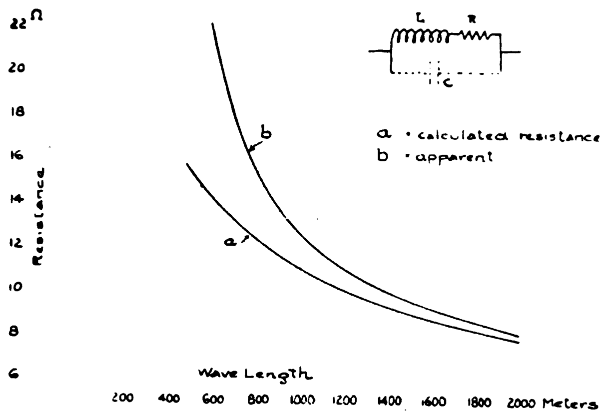


Fig 6

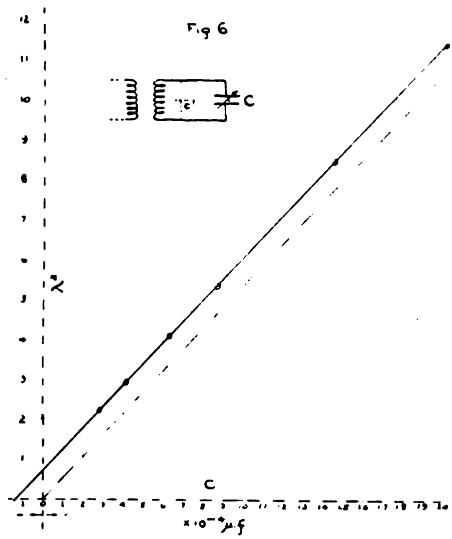
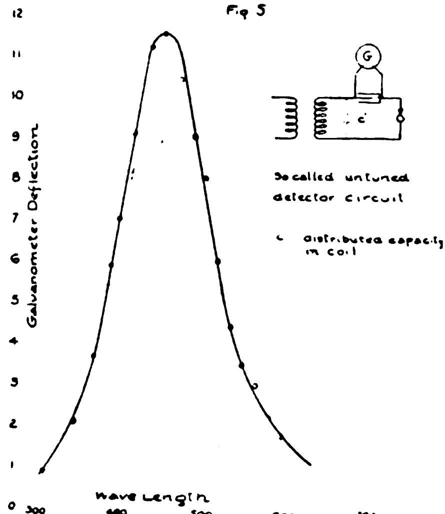


Fig 5



in an article written by Professor G. W. O. Howe in the Proceedings of the Physical Society of London.

A variable condenser of known capacity is connected to the coil under observation and the circuit is excited at various frequencies. A curve as shown in Figure 6 is plotted with values of condenser capacity as abscissae and the squares of the wave lengths as ordinates. A straight line is obtained which, instead of striking the horizontal axis at zero, which would be the case if no distributed capacity existed in the coil, gives the negative value of C corresponding to a value zero for the square of the wave length. This negative value is the effective capacity of the coil.

The true value of the inductance of the coil may also be determined from the broken line shown in Figure 6, drawn parallel to the observed line, through C equal to zero. Taking value of λ^2 as determined by this broken line for various values of C, and averaging the results from the usual formulae

$$L = \frac{\lambda^2}{4\pi^2 v^2 C}$$

the value of the true inductance is obtained.

The curve in Figure 6 was obtained for the same coil as in Figure 1, and the values for the effective capacity and true inductance of this coil as determined by these two methods agree almost exactly.

The results of these experiments show the importance of taking into consideration the capacity effects in coils of circuits designed for calibration and standardizing purposes, and in particular in circuits of large inductance and small capacity.

Inductance coils for radio-frequency circuits should be designed to have minimum capacity as well as minimum resistance. It is unfortunate that the best design for one of these requirements is generally not the best design for the other.

Coils with "dead-ended" turns should not be used, even though the turns not in use are metallically disconnected from the circuit. They should be entirely out of the field of the active turns.

Coils in so-called untuned detector circuits should be particularly designed to have minimum capacity or else for each short range of wave lengths a separate coil should be used having a natural period best adapted to this range.

SUMMARY: It is shown experimentally that an induc-

tance having distributed capacity may be practically replaced by an inductance (called its "true inductance") in parallel with a capacity, (called its "effective capacity"). Methods of calculating each from observations are given and it is shown how strong response to one or more frequencies in wave meter and so-called untuned detector circuits is caused by distributed capacity inductances, particularly those with dead-ends. Practical conclusions are drawn.

DISCUSSION.

ALFRED N. GOLDSMITH: The assumption made by Mr. Kolster that an inductance having distributed capacity may be for electrical purposes replaced by a definite inductance in parallel with a definite capacity can be true only when the inductance is reasonably localized and the capacity not extremely great. It certainly cannot hold in unmodified form for radiative antennae. By experiment it has been shown to be a valid assumption (within the errors of measurement) for practically non-radiative coils of moderate dimensions.

An interesting fact concerning an open or radiative circuit, that is, one containing large distributed capacity, is that the frequencies of the alternating currents produced in such a circuit when it is coupled to a closed oscillating circuit cannot be correctly calculated from the equations holding for closed coupled circuits, and that the frequencies of the overtones produced in the open circuit are not integral multiples of the fundamental frequency. (See L. Cohen, Bulletin Bureau of Standards, Vol. VI, No. 2, 1909).

GREENLEAF W. PICKARD: Distributed capacity effects in inductances are important radio apparatus, and are usually detrimental. While it is obvious that such capacity cannot be entirely eliminated, it may be minimized in various ways. Multiple layer coils of ordinary construction have excessive distributed capacity, and many more or less successful attempts have been made to decrease this. Certain early patents in this art show multiple layer coils, wound in a peculiar manner, each section of the coil having its layers

pyramided, so to speak. Such a construction is indeed a partial solution of the problem, and it is interesting to note that although these patents are now some fourteen years old, a similar method of winding is now being introduced as a novelty.

Occasionally the distributed capacity of a coil may be made to serve some more or less useful purpose. An example of this is the early Slaby wave-meter, consisting merely of an "open" coil, with no capacity other than that of the winding.

EMIL J. SIMON: Will Mr. Kolster describe the various methods of partially avoiding distributed capacity, for example, the use of banked turns?

FREDERICK A. KOLSTER: I did not propose to go into that matter in detail in the present paper. Banking or interweaving of the turns is of value. The reason therefor seems to be that the potential differences between adjacent turns of wire are reduced by this method of winding.

In wave meter circuits, coils having distributed capacity should not be partly inside and partly outside the instrument. They should be connected directly and entirely to the variable condenser, for then the main effect of the distributed capacity will be merely a small addition to the capacity of the variable condenser.

ROY A. WEAGANT: In the experiments, what was the source of oscillations?

FREDERICK A. KOLSTER: Buzzers or quenched gap exciters were employed.

ROY A. WEAGANT: Were any experiments made at various decrements to determine if the effects were altered?

FREDERICK A. KOLSTER: It was found that the smaller the decrement of the transmitter, the more pronounced the results became. The decrement of the exciting circuit containing the quenched gap was 0.008.

ROY A. WEAGANT: There was a case when the closed oscillating circuit showed apparently infinite impedance?

FREDERICK A. KOLSTER: There was such a case. In the arrangement shown in Figure 8, where L_2 is coupled to the exciting circuit, A is the current indicator, and L_3 the coil having distributed capacity, the apparent resistance of the

Figure 8

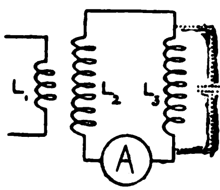


Figure 9

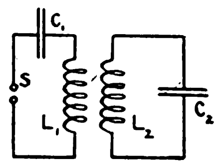


Figure 10.

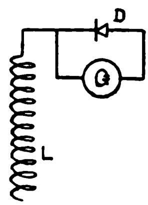


Figure 11

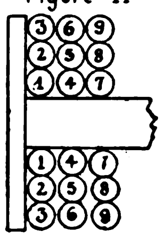


Figure 12

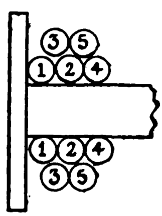


Figure 13

Figure 14

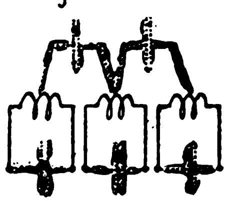


Figure 15

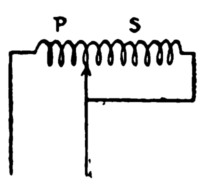
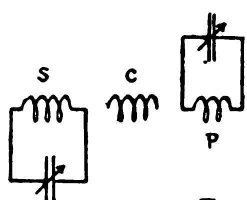


Figure 16



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loop circuit at certain frequencies as indicated by the current readings, was in the megohms.

BENJAMIN LIEBOWITZ: How were the capacity and true inductance of the coils measured?

FREDERICK A. KOLSTER: Professor Howe found the free period of the coils he used by exciting the coil and attaching a vacuum tube to one of its terminals. A method which I have employed is shown in Figure 10. L is the coil, the natural period of which is to be determined, G a galvanometer connected to a rectifier D. When the maximum deflection is obtained in the galvanometer, the periods of the coil L and the exciting circuit are equal (for very loose coupling). If the inductance of the coil, measured at a very low frequency, say 100 cycles, is known, then having measured its natural period, its capacity may be calculated. However, it is best to use Professor Howe's method, as described in the proceedings of the Royal Society, or else to determine the equivalent loop circuit, as I have shown in my paper.

H. E. HALLBORG: Can you excite the coil with a buzzer and measure the wave length with a wave meter?

FREDERICK A. KOLSTER: That method is dangerously unreliable.

ROY A. WEAGANT: In obtaining the resonance curve in the aperiodic circuit containing a detector, were the resonant effects obtained certainly due to distributed capacity, as you have stated, or might they not be due to a gradual change of decrement in the exciting circuit?

FREDERICK A. KOLSTER: The observations were too marked to be due to decrement changes. The measurements were quantitative, a thermo-couple and galvanometer being used for the indicators.

ROY A. WEAGANT: It seems to me that with the coupling values fixed, there would be a change of indication (a gradual increase) as the wave length was altered because of change of coupling.

FREDERICK A. KOLSTER: The effect was not that of a gradual increase. It was a distinct peaked curve in a limited range of wave lengths.

EMIL J. SIMON: There are a number of ways of reducing distributed capacity through the banking of turns. Two are shown in Figures 11 and 12. The numbered circles repre-

sent the cross sections of consecutive turns, wound in the order indicated. Each of these methods of winding is somewhat difficult to construct mechanically, but the second method is preferable in that regard.

GUY HILL: Have you tested transmitting apparatus for these effects?

FREDERICK A. KOLSTER: Yes, and the effects found were similar.

H. E. HALLBORG: If we have the arrangement shown in Figure 13, did you find that the distributed capacities add when the coils are connected in series?

FREDERICK A. KOLSTER: The arrangement shown is probably equivalent to that represented diagrammatically in Figure 14. There the distributed capacity of the coils are shown connected directly across the coil terminals, and the "mutual capacities" of the individual coils are shown connected from coil to coil.

ALFRED N. GOLDSMITH: Such systems as that shown in Figure 13, if the distributed capacities are large, have a great number of degrees of freedom and will respond more or less powerfully to many frequencies. In practice, this may lead to flat tuning.

H. E. HALLBORG: The distributed capacity in the secondary of an ordinary high tension transformer may be a direct cause of breakdown if the transformer is feeding a circuit in which there are radio frequency currents of certain definite periods. At Brant Rock there was employed at one time a 100 kilowat 12,500/25,000 volt transformer, tested by the manuturer to three times the rated voltage. At a wave length of 1,500 meters, it was impossible to operate this transformer without breakdown of the internal secondary coils unless a large choke coil was connected in series. At 3,700 meters no choke coil was necessary, although one was used. I attributed the phenomenon to internal resonance at a frequency corresponding to the 1,500 meter wave length. The coils had large distributed capacity, being step wound. Break-down always occurred in the same coils and at the same wave length. A choke coil in series reduced the period to a point where no resonance occurred through the range of wave lengths used and therefore made operation safe for these frequencies.

GREENLEAF W. PICKARD: I should like to ask Mr.

Kolster's opinion of the relative merits of the methods shown in Figures 13 and 15, for avoiding the "dead-end" effect of the unused portion of an inductance coil. In Figure 13, the inductance is sub-divided into a number of small sections, which are successively connected together and to the circuit; while in Figure 16, the required amount of inductance is placed in the circuit, and the remainder of the coil, or a considerable portion thereof, is short-circuited.

FREDERICK A. KOLSTER: The inductance made up of many small sections disconnected from the rest is better. Short-circuiting is perhaps a good thing if it is necessary to have the unused portions of the coil inductively linked to the active turns.

ROY A. WEAGANT: Does not the short-circuiting method give rise to large damping?

FREDERICK A. KOLSTER: It may well do so. Still, I should prefer to short-circuit unused portions of the circuits which could not be bodily removed.

GUY HILL: I tried the short-circuiting method and found no marked losses.

CHARLES A. LE QUESNE, JR.: As a matter of fact, in receiving, short-circuiting a number of turns sometimes helps.

ROY A. WEAGANT: The improvement in strength of signals which is thus obtained can always be surpassed by a direct change of inductance, capacity and coupling in the circuits. The short-circuiting method is not a desirable way of tuning. In some cases I found that a single short-circuited turn caused a 10 to 50 per cent. diminution in the strength of the signals.

GREENLEAF W. PICKARD: If the resistance of the coil is small, the effect of short-circuiting a section is small. If an active portion of the coil is short-circuited, the effect will be greater.

ROY A. WEAGANT: If as much as 25 per cent. of the coil is in use, I found that only a few turns need be short-circuited to completely spoil the signals.

FREDERICK A. KOLSTER: After short-circuiting the additional turns, Mr. Weagant, did you retune the circuit?

ROY A. WEAGANT: I did. I always made a series of adjustments with and without short-circuiting.

ALFRED N. GOLDSMITH: It will be noted that Figure 15 represents an auto transformer, of which P is the primary and the entire coil the secondary. Short-circuiting a portion of the secondary according to the well-known theory the transformer, increases the apparent resistance of the primary and diminishes the apparent inductance of the primary by calculable amounts. The result in our case is that both the damping and period of the primary circuit are altered, and retuning and variation of coupling are necessary if a fair comparison is to be made between the methods shown in Figures 13 and 15.

But, á priori, the general theory of the conservation of energy indicates that the short-circuiting method is the less desirable one.

ROY A. WEAGANT: The effects actually observed were always as Dr. Goldsmith has stated.

FREDERICK A. KOLSTER: As an example of a coil intended for work in ranges of frequencies to which it was actually resonant, I may mention one of 100 turns wound 32 to the inch, on a threaded rubber spool 4 inches in diameter. The unused turns were wound up and short-circuited on a metal spool. The fundamental wave length of this coil was 300 meters! This was due to the neighboring metal cylinder.

GREENLEAF W. PICKARD: It may be of interest in this connection to describe a method of measuring the natural period of a coil, which does not involve any attachment to the coil. In many cases, the capacity of the coil is so small, that the addition of even a few inches of wire to one terminal will have a marked effect on the natural period. I have shown this method in Figure 16, where the coil C, under test, is placed between an exciting circuit C and a receiving circuit S, the distance between coils being, in some cases, several feet.

When circuits P and S come into resonance with coil C, this coil either acted as an absorbing screen, diminishing the current in S, or, with certain forms of coil and relative positions of the three circuits, a marked increase of current in S occurred at the resonant point. In either case, the resonant point was so sharply marked that an excellent determination of the natural frequency of the coil C could be made.

This reversal of effect is probably due to the combination of electrostatic and magnetic coupling between C and S. The

energy in S was measured by detector and galvanometer in the usual manner.

LESTER ISRAEL: If the resonance point is determined by maximum deflection when the electrostatic coupling is predominant, and by a minimum when the magnetic coupling is predominant, will there not be some position where no indication of resonance can be obtained?

GREENLEAF W. PICKARD: Experiments for determining this were not tried. It might readily be investigated by rotating or otherwise moving C, so that the electrostatic and magnetic couplings were differently varied.

H. E. HALLBORG: (By Letter). Since the delivery of Mr. Kolster's paper, I have found by measurement that the distributed capacity of two similar coils is half that of one, obeying the same law as condensers in series; and when connected in parallel, double. The exact value varies with the degree of electrostatic and magnetic coupling between the coils under consideration, as Mr. Kolster has stated. Hence, with a straight coil of considerable length, the distributed capacity of the coil as a whole falls off in a definite proportion to the increase in coil length or number of turns.

As regards the method which I mentioned for directly determining the frequency of a coil by exciting it with a buzzer, the reverse method yields surprisingly good results. The wave meter was excited by a buzzer, and reception was accomplished by a crystal hanging at one end of the coil under test. By adding a condenser of known capacity in parallel with the coil and taking a second reading, we can separate the distributed capacity and the true inductance of the coil.

(Editor's Note: The method employed for finding the free period of a coil in the Radio Engineering course at the College of the City of New York is by exciting the coil under examination from an APERIODIC buzzer circuit loosely coupled to it. This is, in effect, simply impulse excitation, and the results obtained have been highly satisfactory both in manipulation and accuracy. The unreliability of buzzer excitation is thus completely removed.

THE RELATION BETWEEN EFFECTIVE RESISTANCE AND FREQUENCY IN RADIO TELEGRAPHIC CONDENSERS.

By Louis W. Austin, Ph.D.
(*Head of the United States Naval Radiotelegraphic Laboratory.*)

In a former article [1] I described some experiments on the effective resistance of certain condensers used in radiotelegraphy. In these condensers two types of energy loss appeared, one of which, the brushing loss, increased as the square of the voltage; while the second the dielectric loss, was independent of the voltage between the limits of 4,000 to 20,000 volts No attempt was made in these experiments to determine the effect of changing the frequency, the only wave length used being approximately 1,000 meters.

It is, of course, well known that the dielectric conductivity of condensers at commercial and telephone frequencies, 60 to 5,000 per second, increases nearly in proportion to the frequency [2]. So far as I am aware, however, no attempt has been made to examine this point in the range of radiotelegraphic frequencies.

During some experiments a few months ago on the effective resistance of glass plate condensers immersed in oil some anomalies were observed which led to observations being made on the effect of wave length on the resistance. It was at once found that the effect was very marked, and further observation showed that the resistance at a given wave length was the same whether the measurements were made at several thousand volts or at the low voltages produced by a buzzer circuit.

As the buzzer method of excitation for experimental purposes is far more convenient than that involving spark apparatus, the following measurements were carried out by this method. The arrangement of the apparatus is shown in Fig-

(1) Bulletin, Bureau of Standards, IX, Page 73, 1912.
(2) J. A. Fleming, Journal of the Inst. of Elec. Engineers, London, 49, page 323, 1912.

ure 1. Here A is the buzzer circuit, and B the experimental circuit, consisting of an inductance L, a low resistance thermo-element Th, with its sensitive galvanometer; and a double switch s-s by means of which either a variable air condenser C, or the condenser under test X can be thrown into the circuit. In series with air condenser C are mercury cups by means of which fine wire resistance units R can be thrown into circuit.

The method of observation consists merely of tuning the circuit B to A for the wave length desired with the switch thrown so as to connect the unknown condenser X. The deflection of the galvanometer is noted, after which the condenser X is replaced by the air condenser C and resistance inserted at R until the galvanometer deflection becomes the same as that first observed with the condenser X in circuit. As the air condenser may be considered free from resistance, R represents the "effective or dissipative resistance" of X.

Table 1 gives the observed resistance of a copper-coated glass plate condenser of 0.00196 mf. capacity with a copper coating of an area of 30.8 cm. by 30.9 cm., while the thickness of the glass dielectric is 0.296 cm.

TABLE I.

WAVE LENGTH	FREQUENCY	RESISTANCE	S (OBSERVED)	S (CALCULATED)
385 meters.	779,000	0.7 ohms	1.4	1.16
650	461,500	1.3	0.77	0.69
910	329,000	2.0	0.50	0.49
1325	226,000	3.0	0.33	0.34
1905	157,200	4.8	0.21	0.23
2360	127,000	5·4	0.18	0.19
3100	96,770	7.5	0.13	0.143

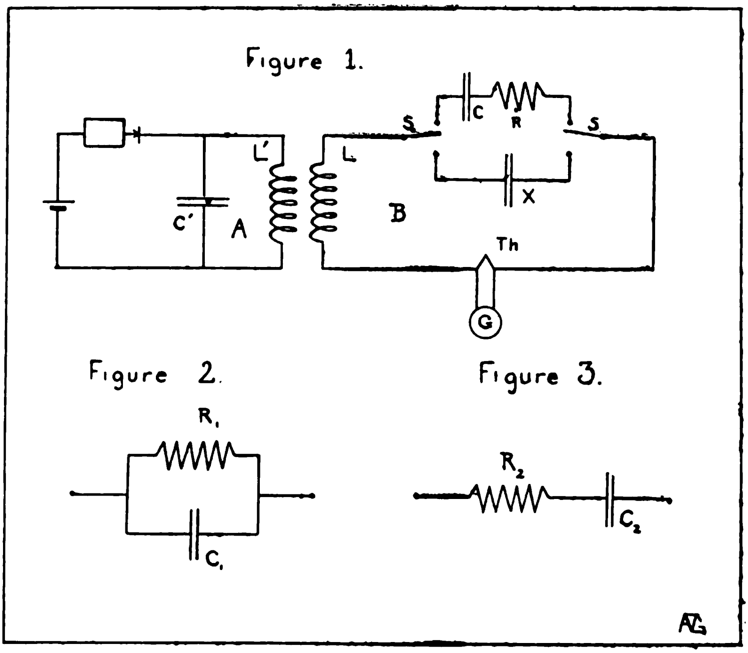
If we let S represent the conductivity, the reciprocal of the resistance, then, according to the results of Fleming, the

dielectric conductivity can be represented by a formula of the form

$$S = A + B n$$

where A and B are constants and n the frequency. For good dielectrics, A in general is small and with such high frequencies its exact value would be difficult to obtain. Assuming that A is equal to zero, the value of B for our observations would be $1.49(10)^{-6}$ and our results would be represented by

$$S = 1.49(10)^{-6}\, n.$$



According to this formula, the resistance of this condenser at 60 cycles would be approximately 12,000 ohms. A similar condenser of practically the same dimensions and quality of glass was measured at the Bureau of Standards and found to have a resistance of 53,000 ohms. While this numerically differs considerably from the value indicated by our formula, it is still of the same order of magnitude, and it seems that the agreement is remarkable considering that the range of frequency in the two experiments varied between 60 cycles and 779,000 cycles.

TABLE II.

WAVE LENGTH	FREQUENCY	RESISTENCE	S (OBSERVED)	S (CALCULATED)
910 meters.	329,000	0.5 ohms	2.0	1.81
1325	226,000	0.9	1.1	1.24
1905	157,200	1.1	0.91	0.87
2360	127,000	1.4	0.71	0.70
3100	96,770	2.0	0.50	0.53

Observations were also made on a copper-coated Leyden jar of 0.00176 mf. capacity. (Table II). The coatings have a height of 25 cm. The diameter of the jar is 12.05 cm. and its thickness 0.292 cm. The conductivity of this par can be represented by

$$S = 5.5(10)^{-6}\ n.$$

TABLE III.

WAVE LENGTH	FREQUENCY	RESISTANCE	S (OBSERVED)	S (CALCULATED)
650 meters.	461,500	2.5 ohms	0.40	0.59
910	329,000	3.0	0.33	0.42
1325	226,000	3.6	0.28	0.29
1905	157,200	4.3	0.23	0.21
2360	127,000	4.8	0.21	0.16
3100	96,770	6.5	0.15	0.13

In Table III are given the resistances of an old Murdock condenser which has seen much service. Here the conductivities do not seem to follow the same relationship as exactly as in the case of the glass condensers of the same type measured a year ago, [1]. The resistance is much greater than was found in new condensers.

Additional observations were made on the dissipative dielectric resistance of glass plates in series and in parallel. As was to be expected, it was found that condensers in series show a total resistance equal to the sum of the individual resistances, while in parallel, the total resistance is equal to the single resistance divided by the number of plates, exactly as would be the case in metallic resistances. This differs from the case of the brushing resistance, which was found proportional to the number of plates, [1]. This shows that if condensers be arranged in series parallel, for the same capacity the dielectric resistance will remain the same as for a single condenser.

(1) Bulletin, Bureau of Standards, IX, Page 73, 1912.

While the resistance of the single condenser may be considerable at the longer wave lengths, in practice this is not disturbing, since the high power sets employed for long wave work would require so great a capacity that the resulting resistance would be practically negligible.

U. S. Naval Radiotelegraphic Laboratory.
Washington, March, 1913.

DISCUSSION.

(By Letter)

PROFESSOR A. E. KENNELLY: The excellent paper of Dr. Austin indicates, among other things, that a simple buzzer may serve as a valuable source of electric waves, of adjustable frequency, for testing purposes.

The results obtained for the losses in the condensers seem to indicate that it is simpler to conceive of these losses as due to an equivalent leakage conductance, in **MHOS** rather than to an equivalent series resistance in **OHMS**. Moreover, the Fleming constants, A and B, of this equivalent leakage conductance, can then be readily expressed, and tabulated or compared. The constant A would be a pure conductance in mhos, and theoretically might be found at zero frequency, or as a direct current leak. The constant B would be expressible as mhos-per-cycle-per-second. In the case of the first condenser examined in the paper, A would be negligible, and B would be 1.49 micromhos-per-cycle-per-second; whereas in the last case given, B would be 5.5 micromhos-per-cycle-per-second. For an air condenser, B would be nearly zero.

In this way, the leakiness of a condenser to high frequency currents would become saliently expressed. If two such condensers were in parallel, their B constants would add together; but if they were in series, the reciprocal of their sum of reciprocals would be taken. With "brushing" resistances present, the conditions would be more complex, as Dr. Austin indicates.

This paper might properly be referred to the Committee

on Standardization of THE INSTITUTE OF RADIO ENGINEERS for suitable recognition and action.

LLOYD ESPENSCHEID: In interpreting the results of these measurements it is of advantage to bear in mind the physical significance of the quantities involved. The conductance expression.

$$S = A + Bn$$

indicates that there are two components to the dielectric dissipation factor. One (represented by A) is due to the direct conductance through the dielectric material, and the other (represented by B) to the dielectric hysteresis, or molecular friction. In terms of resistance these components correspond respectively to the $R_{d.c.}$ and the $\triangle R_{a.c.}$ of an inductance coil.

The impedance of a condenser having energy losses may be represented by an equivalent impedance having the components R and C connected either in parallel or in series.

Starting with the parallel arrangement (shown in Figure 2) the admittance of the condenser is

$$2 \pi n C_1 = \omega C_1$$

and the conductance of the resistance is

$$S_1 = \frac{1}{R_1}$$

so that the impedance of the combination may be written in terms of conductance and admittance, thus—

$$Z = \frac{1}{S_1 + j \omega C_1} = \frac{S_1 - j \omega C_1}{S_1^2 + (\omega C_1)^2}$$

In the case of the series arrangement, (as shown in Figure 3) which applies to the form in which Dr. Austin's measurements are given, we have

$$Z = R_2 - j \frac{1}{\omega C_2} = \frac{S_1}{S_1^2 + (\omega C_1)^2} - j \frac{\omega C_1}{S_1^2 + (\omega C_1)^2}$$

which give us the expressions connecting the series and parallel circuits.

Considering the effective resistance components, namely

$$R_2 = \frac{S_1}{S_1^2 + (\omega C_1)^2}$$

since the numerator (S_1) varies only directly with the fre-

quency, and the denominator varies as the frequency squared, R_2 goes down as the frequency goes up. This is in agreement with Dr. Austin's results.

We may express the series resistance R_2 in terms of the parallel resistance and capacity, instead of parallel conductance and capacity, thus:

$$R_2 = \frac{R_1}{1 + (R_1 \omega C_1)^2}$$

Since R_1 varies inversely with the frequency, the factor $(R_1 \omega C_1)^2$ remains constant and therefore R_2 varies inversely with the frequency.

Looking at it in another way, in the range of radio frequencies we should expect the impedance angle of the condenser to remain practically constant, and since the capacity reactance varies inversely with the frequency, the resistance should vary likewise.

At constant voltage the energy loss ($I^2 R$) increases with the frequency because the current squared increases more rapidly than the resistance decreases. At constant current, the loss ($I^2 R$) decreases with increase of frequency because the resistance decreases.

Messrs. **LESTER ISRAEL** and **ALFRED KUHN** contributed (independently) the following discussion:

The dielectric resistance of a condenser can be found from the effective dissipative resistance of that condenser as follows:

The current in the secondary of two very loosely coupled circuits is given by Bjerknes as

$$I^2_{eff.} = N \frac{E^2}{16\, n^3\, L_2^2} \cdot \frac{1}{d_1 d_2 (d_1 + d_2)}$$

where N is the number of times the condenser is charged per second,

E is the voltage applied to the secondary,

L_2 is the inductance of the secondary,

d_1, d_2 are the decrements of primary and secondary, respectively,

n is the frequency.

Since none of the other factors is changed, d_2 must be equal in the cases shown in Figures 2 and 3, assuming equality

of current in the secondary in these cases. That is, when the air condenser and resistance in series are substituted for the Leyden jar (which is in effect a capacity in parallel with a resistance), the damping of the circuit is unchanged.

The differential equation holding for the circuit of Figure 3 is

$$L \frac{d^2 i}{d t^2} + R_2 \frac{d i}{d t} + \frac{i}{C_2} = O$$

the solution of which leads to the following values for the frequency n_2 and the decrement d_2 in this case:

$$n_2 = \sqrt{\frac{1}{L C_2} - \frac{R_2^2}{4 L^2}} \qquad \text{..................(1)}$$

$$d_2 = \frac{R_2}{2 L n_2} \qquad \text{..................(2)}$$

By considering that in the case shown in Figure 2 the sum of the currents in the branches R_1 and C_1 is equal to the current thru the outside inductance, the following differential equation for this circuit is obtained:

$$L \frac{d^2 i}{d t^2} + \frac{L}{R_1 C_1} \frac{d i}{d t} + \frac{i}{C_1} = O$$

the solution of which leads to the following values of the frequency n_1 and d_1 for this case:

$$n_1 = \sqrt{\frac{1}{L C_1} - \frac{1}{4 R_1^2 C_1^2}} \qquad \text{................ (3)}$$

$$d_1 = \frac{1}{2 R_1 C_1 n_1} \qquad \text{..................(4)}$$

Equating the decrements and assuming, as experimentally arranged, that the frequencies n_1 and n_2 are equal, we have

$$\frac{R_2}{2 L n_2} = \frac{1}{2 R_1 C_1 n_1}$$

or

$$R_1 = \frac{L}{C_1} \cdot \frac{1}{R_2} \qquad \text{..................(5)}$$

Taking Dr. Austin's results as given in TABLE I and calculating R_1 from equation (5), we get the following table:

WAVE LENGTH λ	INDUCTANCE L_2	R_1 (OHMS	R_1/λ
385 m.	21,400 cm.	15,600	40.2
650	60,900	23,900	36.3
910	119,500	35,000	33.4
1325	252,000	43,000	32.2
1905	543,000	57,800	29.0
2360	802,000	75,800	31.9
3100	1,390,000	91,000	30.2

By plotting R_1 against λ, or by examination of the last column of the above table, it will be seen dielectric resistance of a condenser increases with the wave length, that is, the dielectric resistance is inversely proportional to the frequency.

(Editor's Note: Mr. Alfred Kuhn also showed that a relation between R_1 and R_2 identical with that given above is obtained by equating either the frequencies of the circuits from equations (1) and (3) and neglecting terms which are extremely small under the conditions of these tests, or by equating the energy consumption in the two cases shown in Figures 2 and 3.)

ALFRED N. GOLDSMITH: The following are some of the possible sources of error in an experiment of this kind and the methods of eliminating them:

1. Losses due to eddy currents in the plates and connectors of the standard condenser, C_2, which will result in an apparent value of R_1 smaller than the true value. The importance of these losses can be gauged by substituting for the standard condenser one whose plates are of a different and preferably much more resistant metal, but which is otherwise identical.

2. Large inductance in the leads and plates of the standard condenser cause the apparent value of R_1, to be larger than the true value. This effect may be minimized by properly arranging the connections and by employing a compact condenser, that is, one with (circular) plates at small separation.

3. The curve of current (i. e., the current wave form) may not be the same in the two cases because of the fact that the dielectric resistance is not a pure ohmic resistance but may vary during the current cycle. Detailed investigation of this effect using, for example, a Braun tube oscillograph is desirable.

And finally, an interesting method of verifying Dr. Austin's valuable results quantitatively would be by calorimetric measurements. The immersion of the condenser under test in an oil bath and the measurement of the temperature rise under known current and other physical conditions would enable the direct calculation of R_1.

Volume I

Part 3

PROCEEDINGS

OF THE

INSTITUTE OF RADIO ENGINEERS

CONTENTS:

EDITED BY

ALFRED N. GOLDSMITH, Ph. D.

NEW YORK, JULY, 1913

Manuscripts and letters bearing on the Proceedings should be sent to Alfred N. Goldsmith, Editor of Publications, College of the City of New York, New York.

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* The cost of separate copies of the Proceedings is $1.00.
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THE SEIBT DIRECT INDICATING WAVE METER.*

By Emil J. Simon and Dr. Alfred N. Goldsmith

A conducting ring placed in front of a coil in which flows an alternating current will be repelled from the coil. The cause of the repulsion is the interaction of the current induced in the ring by the alternating magnetic field in which it is placed, and the magnetic field itself. This repulsion is known as the Thomson [1] or dynamometer effect. The exact magnitude of the effect, and the conditions under which it is most readily produced and measured, can be ascertained from the articles mentioned in bibliography at the end of this article. The industrial applications of the dynamometer effect have been many. In a braking device on induction motors and in alternating current wattmeters it has been widely utilized. It has even been employed by Mandelstam and Papalexi [2] in a special form of double, alternating current, mirror galvanometer whereby the radio frequencies can be very precisely measured. Tho measurements of wave length by the method of Mandelstam and Papalexi are of a high order of precision, the convenience of their method is hardly as great as that of the familiar method of Bjerknes, and it is not well suited for use except under laboratory conditions. A pointer and scale instrument of this type would be difficult to construct. It has remained for Dr. George Seibt to place on the market a wave meter based on the Thomson effect, portable, and direct indicating. We shall describe this instrument in further detail.

As shown in Figure 1, when an alternating current passes thru the coil S, the ring R will be repelled. If two coils, S_1 and S_2 (Figure 2), be placed on opposite sides of the ring R, they will exert on this ring the opposing forces K_1 and K_2. If the ring is free to move it will assume an intermediate position of equilibrium between the two coils. If the two coils are alike,

(1) Elihu Thomson, Electrical World, May 28, 1887.

(2) Mandelstam and Papalexi, Annalen der Physik, 1910, Vol. 33, Page 490.

*Partially based on Dr. George Seibt's French Patent No. 446,251 and English Patent No. 16,874.

Figure 1

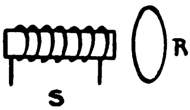


Figure 2

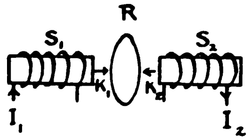


Figure 3

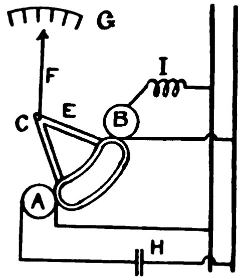


Figure 4

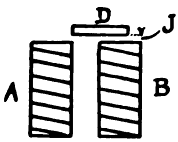


Figure 5

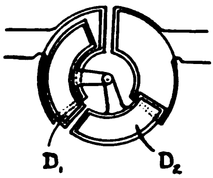


Figure 6

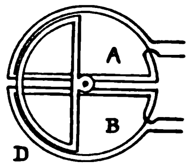


Figure 7

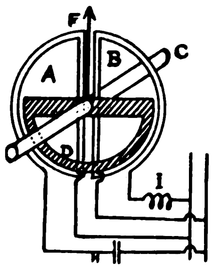


Figure 8

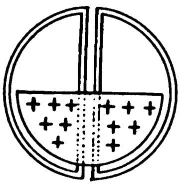
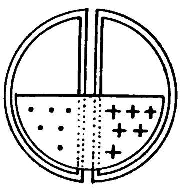


Figure 9



the currents thru them equal, and if no external control force acts on the ring, it will place itself exactly half way between the coils. But if the currents are unequal, the ring will move toward the coil carrying the smaller current. The problem of constructing a wave meter on this basis then resolves itself into the following: What arrangement of circuits connected to the coils S_1 and S_2 will ensure a division of the total current between them, such that the relation between the currents in S_1 and S_2 shall be dependent only on the frequency of the total current, but not on its magnitude?

A number of methods of constructing the instrument will be given. Referring to Figures 3 and 4, coils A and B are placed approximately 90° apart relative to the axis C of the instrument. Over them is mounted on the frame E the armature D, consisting of a piece of metal forming a closed circuit or of a number of short-circuited windings. Both armature and frame are free to rotate about the axis C, carrying with them the pointer F, which moves over the graduated scale G. It will be seen that this arrangement is equivalent to that shown in Figure 2, inasmuch as an alternating current thru either coil A or B will tend to repel the armature D toward the other coil. As before, the stable position of the amature is determined by the relation between the currents in the coils A and B or the fields due to these currents.

The variation of the fields or of the currents with the frequency may be obtained in various ways other than that mentioned above, which was finally adopted. Thus the coil A may be connected to the circuit the frequency of which is to be determined thru the condenser H, and the coil B thru the inductance I.

The form of armature construction shown permits of placing it very close to the coils A and B. The closeness of coupling between the coils and the armature can be varied by altering the distance J.

The sensitiveness of the instrument and also the operative angular range on the graduated scale are increased if the surface enclosed by the armature, and also the surface enclosed by each of the coils A and B, subtends a greater angle at the center than 90°. In Figure 5 is shown an arrangement in which the surface of the armature and coils of the instrument are angularly measured, and relative to the axis of the instrument,

each greater than 90°. The armature is here split into two parts D_1 and D_2. The theoretical maximum angle of deviation is 120°; but in practice, owing to the weakening of the forces of deflection at larger angles of deflection and the consequent inaccuracy in the readings of the instrument, deflections greater than about 60° are not used. The arrangement shown in Figures 6 and 7, in which the surface of the armature and fixed coils are, angularly measured relative to the axis of the instrument, about 180° wide is still more sensitive. The maximum theoretical angle of deflection reaches 180°, and the maximum angle used in practice about 110°.

Another possible way of constructing the armature is to shape it as part of a cylindrical surface, the axis of which is the axis of the instrument at the pivot. The surface of the armature is then parallel to the axis of the instrument, and the end surfaces of the fixed coils are preferably arranged also to be parallel to this axis.

An interesting phenomenon which has been observed in connection with the arrangement shown in Figure 7 may be here mentioned. If the coils A and B are so connected that their fields have one and the same direction and are in phase with each other, the armature does not come to rest in some intermediate position of equilibrium as before. It swings toward the coil carrying the smaller current, and comes to lie entirely in the field of that coil with the pointer thrown against one end of the graduated scale. This condition is shown in Figure 8. The lines of force are represented as circles or crosses, depending on whether they are to be regarded as emerging from the plane of the paper or entering it. If the fields of the fixed coils are equal to each other, the resultant force *tending to produce rotation* of the armature is zero independently of the position of the latter. There will therefore be no definite position of rest, the movable armature being in what may be called a "floating" state. The above phenomenon is rendered quite explicable when one considers that, in Figure 8, coils A and B are in effect but a single coil; and that the motion of a conductor in an alternating magnetic field is toward regions of least magnetic force. A careful consideration of Figure 9, wherein the fields of the coils A and B are represented as in opposite phase, leads to the conclusion that we may have an equilibrium position in this case.

The occurrence of the phenomenon of "floating," which may take place even tho large currents are flowing in the armature, would render the instrument practically useless if no means were provided for avoiding it. For example, if we used such an instrument for measuring rapidly alternating currents, the indications would be quite unreliable because the "floating" is caused not by the relation between the absolute values of the currents, but by the relation between the phases of the fields.

Referring again to Figure 7, if the condenser H is made so small that its equivalent alternating current resistance is greater by a certain amount than that of the coil A, then the currents in the coils A and B will have a phase displacement of 180°. Whether the fields will have the same phase displacement as the currents depends on the sense in which the coils are wound, and on the way in which they are connected to the circuit the frequency of which is to be measured. The phase displacement between the fields can always be brought to 180° by simply interchanging the connections of one of the coils.

Experiments have shown that when the arrangement shown in Figure 7 is used to measure the frequency of damped alternating currents, as produced for example by spark discharges, the values obtained are very inaccurate (as compared with the true values of the wave lengths.) The cause of this inaccuracy is that an oscillating circuit is formed by the condenser H, the inductances A and B, and the inductance outside the instrument which serves for coupling purposes. In this circuit free oscillations are induced, these oscillations having in general a different frequency from that to be determined. Calibration of the instrument with sustained alternating current would therefore introduce a continuous error when measuring damped oscillations, the magnitude of this error increasing with the damping of the oscillations, and with the closeness of coupling of the instrument to the circuit of which the frequency is to be measured; since the frequency of the current in the instrument would be a function of the coupling to the exciting circuit.

In order to overcome the serious objection just mentioned, the free oscillations of the instrument are strongly damped. The instrument may even be made completely aperiodic. The damping of the instrument is accomplished by inserting an ohmic resistance in parallel or in series with the condenser, or by entirely dispensing with the condenser. For instance, if the condenser in

Figure 7 is replaced by a non-inductive resistance, the "free period" error is eliminated.

The insertion of this resistance is unfortunately accompanied by an energy loss. This disadvantage may become so great as to prevent the use of the instrument in radio telegraphy, where small energy losses are essential. For example, a wave meter which consumes 50 watts may be said to be unsuitable for such work since that amount of power would be quite sufficient for signalling over a distance of about 100 kilometers, and, as a loss, could be justified only in very exceptional cases.

The energy loss may be reduced by making the resistance to be inserted in the circuit of the coil A very small. The disadvantage which then arises is that the ratio of the currents flowing thru the fixed coils varies but slightly with the frequency, and the divisions on the scale corresponding to the various frequencies are excessively close. This crowded scale is overcome by the arrangement shown in Figure 10. Here a resistance K is arranged in series with the fixed coil A and a resistance L in parallel with the fixed coil B. Theory and experiment have shown that by these means a graduated scale with widely spaced divisions can be obtained, in spite of the fact that the energy consumption is substantially decreased. Another advantage of the arrangement of Figure 10 is that with suitable electrical constants the divisions of the graduated scale can be made substantially equal, so that the deflections are proportional to the wave lengths.

Considering the phase displacements of the fields in the case shown in Figure 10, it is impossible to obtain a displacement of 0° or 180°, the displacement lying between 0° and 90° or between 90° and 180°, without ever reaching the extreme limits. The "floating" effect previously referred to is observed in the arrangement of Figure 10 but to a smaller extent. It is advisable in consequence to lead the currents thru the fixed coils A and B in such a manner that the phase angle is as great as possible, that is to say between 90° and 180°. If, after this has been done the connections to one of the coils is reversed, it can be immediately noticed that the directive force is considerably reduced, and that the armature then tends to "float."

The "floating" phenomenon can occur only when the armature has a well defined circuit reaching into the fields of the fixed coils. A definite circuit is missing in the case shown in Figure 11. The armature being a semi-circular solid disc, each of the

Figure 10

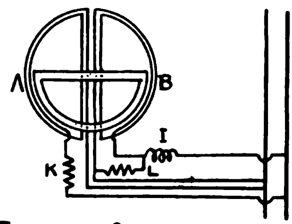


Figure 11

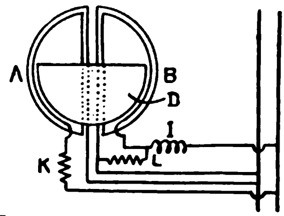


Figure 12

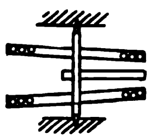


Figure 13

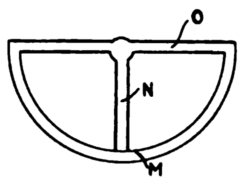


Figure 14

Figure 15

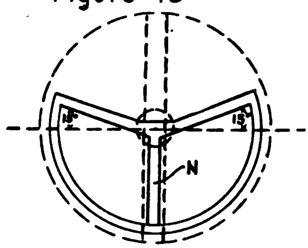


Figure 19

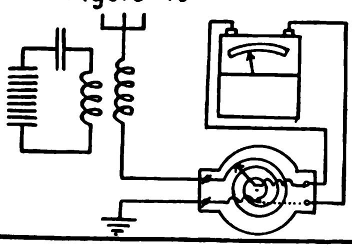
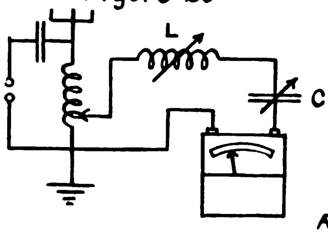


Figure 20



fixed coils will induce in it mainly separate currents. It will be readily seen, however, that this construction is disadvantageous for other reasons. The short-circuited eddy currents, induced by each of the coils, flow within each field radially toward the axis of the instrument and then back toward the periphery with nearly the same strength. The forces produced will nearly neutralize each other, and only a small difference will be left to rotate the armature. It may be stated that the use of a well defined circuit, which is as free as possible from eddy currents, and is under the influence of two fields alternating with a proper phase difference, has been found to be an essential requirement for the success of the instrument. It is further to be noted that if the instrument is constructed in this manner, at most a small current will flow thru the armature after it has reached its position of equilibrium. In the arrangement of Figure 7, no current whatever will flow thru the armature since the phase displacement may be made 180°; and in the arrangement of Figure 10, where this displacement cannot be attained, the armature current can still be made very small by the proper connection to the outside circuit of coils A and B.

In order to attain the requisite sensitiveness, the movable parts of this instrument must be made very light, and for this reason it is desirable to reduce the current in the armature as far as possible to avoid overheating.

To secure still greater sensitiveness and a still wider scale, the modified construction illustrated in Figure 12 is adopted. It will be seen that the fixed coils A and B are mounted slightly inclined to the surface of the armature D. The increased sensitiveness and wider range of the scale are due to the gradient of field intensity, and consequent directive force, found when using this disposition of parts. The condition of equilibrium is that the electromotive forces induced in the armature by the two coils shall be equal and opposite, consequently the angle of rotation will be greater when the field intensity of the coil toward which the armature moves is larger at the entering edge than when it is constant. The inclined coils therefore produce a greater variation in the deflection angle for a definite change in frequency than parallel coils.

To reduce the weight of the armature as far as possible, it has been constructed of sheets of aluminum 0.05 to 0.3 millimeters thick, and this range of thickness has been found satisfactory.

The disadvantage of the construction shown is that the part M (Figure 13) of the armature is easily bent. To avoid this weakness the sheet is formed with a rib, as shown on an enlarged scale in Figure 14, and an insulated reinforced arm N is connected between the parts O and M of the armature, as shown in Figure 13. Instead of using the rib construction, the sheet may be T-shaped, bent into tubular form, or otherwise suitably reinforced. The reinforcement of the armature is especially required in the case where the armature has a surface angularly greater than that of the fixed coils. (Such an increased angular surface increases the sensitiveness of the instrument. For instance if the surface of the armature is increased 15° on each side (as in Figure 15), the resistance in series with coil A can be reduced to half its former value without affecting the range of the scale.)

So far as the form of the fixed coils is concerned, it is advantageous to make them as flat as possible in order to bring the windings into close proximity with the armature. It is also preferable to divide each coil into two separate coils arranged one above the other with the armature lying between them, the separate coils being connected in parallel with each other, and not in series. Their arrangement in parallel prevents the production of high potential differences which might give rise to sparks jumping to the armature or from coil to coil. Moreover, this arrangement reduces the total reactance of the instrument and makes it possible to operate it with small potential differences. The connection of the instrument to existing installations is thereby considerably facilitated.

The wave meter is to be connected in the grounded side of the antenna or other circuit in which high potential differences exist. Experiment has shown that electrostatic forces will slightly influence the movable portion of the instrument; so that, in the absence of a ground connection the instrument should be connected to that point of the circuit where a potential node is found. The error which is produced in the wave meter readings by electrostatic forces may be avoided by exciting the instrument not directly, but inductively by means of a transformer.

A further error in the readings may be caused by the action of powerful exterior fields which pass thru the coils of the meter and alter the distribution of the lines of force. However in the case of radio frequency currents this error can be avoided by surounding the working parts of the instrument by a copper or

aluminum casing; and in the case of low frequency currents preferably by the use of an iron casing.

The scale of the instrument may have more than one range of wave lengths, and the only change necessary in the electrical connections of the instrument in passing from one range to the others is a variation of the non-inductive resistance K of the instrument. This can be readily accomplished by a switch which short circuits a part of the resistance.

In the arrangements so far shown, the fixed coils A and B serve for two functions. Firstly, they induce in the movable armature D alternating currents. And secondly, they produce the turning force on the armature thru the interaction of their fields and the induced currents in the armature.

One can construct a modification of the instrument, wherein the two functions mentioned above are separately performed by individual coils. The coils A and B are semi-circular as before, and serve to induce currents in the armature. They do not, however, exert any appreciable mechanical force on the armature because certain portions R_1 and R_2 of the armature are considerably removed from the neighborhood of the coils. In addition extra coils X and Y are provided in close proximity to the portions R_1 and R_2 of the armature. These coils are intended to produce highly uniform fields, which fields will cause a torque on R_1 and R_2. Coils X and Y may be made semi-circular, but are preferably complete circles, for they will then induce no currents in the armature. Adopting such an arrangement, the energy consumed by the instrument is again substantially reduced and the sensitiveness increased, because the number of turns of the coils A and B may be considerably increased without in any way increasing the energy consumption. The coils of this instrument, when used for radio frequencies are preferably wound with "litzendraht" or multiply stranded wire.

A number of other applications of the constructions given may be mentioned. The instrument may be used as a relay or controlling device. In this case the pointer connected to the movable armature is arranged to press against fixed contacts whenever definite frequencies are reached. The points of the pivot being mounted in insulating bearings, special means of making contact are necessary. This may be accomplished by connecting a very fine and flexible wire to the pivot or by means of double contacts. The instrument may also be employed as a tachometer

or indicating speed meter. It is merely necessary to connect its terminals to a small alternator which is belted or direct-connected to the rotating machinery, the speed of which is desired. The advantage of this instrument as compared to the usually employed voltmeter in tachometers is that the voltage of the alternator of the tachometer may drop considerably thru weakening of the *permanent* field magnets (which are usually used) thereby affecting the reading of the usual instrument. And there is no necessity of calibrating the instrument with the particular alternator to which it is to be connected as is the case when a voltmeter is used as the indicator.

It need hardly be said that in the form of meter used for measuring wave lengths in radio telegraphy no iron cores are employed in the coils. Great care is exercised in this instrument to minimise bearing friction and to balance the armature very carefully.

The portable model of the instrument is shown in Figure 16. The terminals of the instrument are seen on the top. To the right is the switch which, by short circuiting a portion of the resistance permits the use of either the upper or lower scale. The upper scale runs from 150 to 1,500 meters, each division being 10 meters and the lower scale from 500 to 3,000 meters, each division corresponding to 100 meters. Directly above the scales is seen an indicating lamp which serves the following purpose. Theoretically the indications of the wave meter are independent of the current flowing, but in practise it is necessary to keep the current between certain major and minor limits. The objections to a very small current thru the instrument are that there will be no certainty that the friction in the pivots exerts no effect on the reading, that slight unbalancing of the armature is not rendered negligible in its effect, and that the slow motion of the pointer to its final position under the action of small currents makes the reading uncertain. To readily ascertain that the current flowing thru the meter has a correct value, the small indicating tungsten lamp above the scale is watched. This lamp is chosen so that the slightest dark red glow indicates the minimum allowable current, and a bright white light the maximum permissible current. It is not important that any particular degree of brightness be obtained, but in order to obtain long life for the lamp it is desirable to work nearer the lower current limit.

As will be seen from the theory of the instrument, its indications are reliable only when there are alternating currents of a *single* frequency in the exciting circuit. If there are currents of

Figure 16
Seibt Direct Reading Wavemeter—1912 Portable Model

Range { Scale I—300—1500 M
" II—500—3000 M

Figure 17

two or more frequencies present, unless the amplitude of all but one of them are negligibly small, the arrangement shown in Figure 19 must be used. The wave meter is here connected in the resonance circuit L C which is tuned until the lamp brilliancy is a maximum. Two positions where this is the case will be found in an ordinary closely coupled spark set, and the readings of the meter at each of these positions gives the wave length of each of the "coupling" waves. Such an arrangement is naturally unnecessary in the case of quenched spark sets where but a single frequency should be present.

The energy consumed by the form of wave meter shown in the photograph is about 4 watts on the short wave length scale, and about 1 watt on the long wave length scale. A switchboard type of the instrument having the same electrical constants is also constructed. For work covering wide ranges of wave length, the instrument may be built with a scale covering from 800 to 4,500 meters in steps of 100 meters. The even spacing of the scale divisions is seen on Figure 16.

As previously mentioned, the instrument is to be connected in the ground connection of the station. The meter is constructed for currents not exceeding three amperes, and it is usually necessary to connect a purely inductive shunt in parallel with the instrument or else to use a current transformer. Since the amount of inductance required in the shunt is dependent on the current flowing in the antenna circuit, it is always best for a first trial reading to use a very small value of the inductance as a shunt. If no glow occurs in the indicating lamp, the current may be increased by increasing the inductance of the shunt and the process continued until a moderate glowing of the lamp is obtained.

Realizing that this process might be somewhat troublesome in practical work, a specially designed current transformer has been devised which, if properly employed, obviates all risk of burning out the wave meter but still permits of rapid manipulation. The transformer is shown in Figure 18, and the means of connecting it in circuit in Figure 19. The entire ring is connected in series with the antenna at the grounded end and the wave meter is connected to a separate pair of terminals, the inductance across which is adjustable. Because of variations in the antenna current such an adjustment is desirable. These inductive couplers for the wave meter are made in two sizes, and the type used depends on the output of the set with which the wave meter is to

be used. The smaller coupler is for antenna currents of 3 to 30 amperes and is suitable for 2 and 5 kilowatt sets. The larger coupler is intended for use where the antenna current lies between 20 and 100 amperes, and is therefore appropriate for 10 to 50 kilowatt sets.

The advantages of this type of wave meter may be shortly recapitulated: Direct indication of the wave length by a needle moving over a calibrated scale, freedom from adjustment to resonance (unless two waves are present), rapidity of manipulation and reading, readings independent of irregularities in action of spark gap or arc, readings independent of current thru instrument between wide limits, self-contained, light, and rugged construction, long scale, with *even* divisions, long wave length range with high accuracy by use of two scales on the same instrument.

The instrument weighs 5 lbs. (or 2.3 kilograms).

Its dimensions are 9″ by 8″ by 3⅝″ (or 23 cm. by 21 cm. by 9 cm.).

SUMMARY: A direct indicating wave meter depending for its action on the balancing of the repulsive forces exerted by two fixed coils on a movable ring armature is described. Circuit arrangements are shown whereby the division of current between the coils is made dependent only on the frequency. Electrical and mechanical means for increasing the sensitiveness of the instrument, diminishing its energy absorption, obtaining an even wave length scale, and eliminating the so-called "floating effect" are described in detail. Other industrial applications of the instrument are given.

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DISCUSSION.

LEE DE FOREST: Are the indications of this wave meter independent of the applied electromotive force? The currents thru each of the branches must depend on the electromotive force.

EMIL J. SIMON: Dr. Seibt states that theory and practise agree in the conclusion that within certain limits (indicated very well by the glowing of the lamp in the meter) the readings are independent of the applied electromotive force. However, I have found that the readings may be as much as 5% off if the

lamp does not light owing to too loose coupling to the oscillating circuits.

ALFRED N. GOLDSMITH: The reason for this is obviously that sufficiently strong repelling forces are required to render friction at the pivots and air friction negligible in comparison with these forces. Otherwise even a correct choice of the inductances and resistances of the two deflection-controlling circuits will not ensure a correct equilibrium position of the moving system, and one dependent only on the applied frequency.

EMIL J. SIMON: It is found that varying the current thru the instrument between limits of about one-half to three amperes causes no change in the reading provided the frequency is kept strictly constant.

LEE DE FOREST: What are the dimensions of the fixed coils?

EMIL J. SIMON: They are about 5 or 6 cm. (2 inches) in diameter.

LEE DE FOREST: Is the fixed reactance arranged so that its field is far from the armature?

EMIL J. SIMON: The fixed reactance is placed as far away as possible from the armature and at right angles.

LEE DE FOREST: Which of the binding posts is grounded?

EMIL J. SIMON: In practise we use the right-hand post. It is probably connected to the metal lining of the case.

LEE DE FOREST: It would appear as tho Dr. Seibt had tried the resonance type of indicating wave meter first, but unsuccessfully. As regards novelty of the device, he cannot be said to have adopted the frequency meter construction (of the Weston company, for example).

The resonance principle could be applied by placing a light condenser in jewelled bearings in series with an inductance. It would assume the resonance position. Such a device might work up to 100 meters wave length.

ALFRED N. GOLDSMITH: The resonance principle can be applied much more simply, as in the Hirsch direct reading wave meter, made in Berlin by Dr. Erich Huth. It consists, in

brief, of a fixed inductance connected to a rotary variable condenser, the variable condenser being kept in continuous rotation by a small motor. Connected across the terminals of the condenser is a small vacuum discharge tube, which is arranged as a pointer of the variable condenser, and rotates with it. It lights up at the resonance position provided the inductance of the circuit is sufficiently closely coupled to the exciting circuit; and, owing to the effect of persistence of vision, a bright line of light is seen at a certain point of the condenser scale. The condenser scale is graduated in wave lengths. The advantage of this arrangement is that it uses even less energy than the Seibt meter, that the damping of the wave meter circuit is low because the tube is of very high resistance except when it glows at the resonance position, that the damping of the exciting circuit is roughly indicated by the width of the indicating line of light, and that both wave lengths of closely coupled transmitters can be determined, and examined for relative intensities.

H. E. HALLBORG: Such a device might be made in a hand-operated form where it was desired to use it only intermittently.

JOHN L. HOGAN, JR.: Is the wave length indication of the Seibt meter dependent on the damping of the exciting circuit?

EMIL J. SIMON: This point has not been accurately checked, tho measurements on circuits having widely different dampings have been successfully made. It is believed that the indication is entirely independent of the decrement of the exciting circuit.

H. E. HALLBORG: Is connection to the transmitter made thru a fixed coil in the transmitter circuit?

EMIL J. SIMON: The coupling to the transmitter circuit may be either direct or inductive. Seibt uses a 3 turn spiral of 3,000 cm. inductance with a variable contact as an auto transformer. Those so far constructed are usable up to thirty amperes in the transmitter circuit.

ROY A. WEAGANT: Does this wave meter stand continuous service?

EMIL J. SIMON: After using the instrument for two or three hours continuously, no change in the reading was noted.

ROY A. WEAGANT: What is the over-all accuracy of the instrument?

EMIL J. SIMON: Dr. Austin found an average accuracy thru the entire scale from 200 to 3,000 meters of 1%. The meter certainly does not stand excessively rough treatment. Readings should be taken in the horizontal position. Such readings differ by 1 to 2 per cent from those taken in the vertical position.

The upper scale of the meter reads from 150 to 1,500 meters, the lower scale from 500 to 3,000 meters.

It was found that the instrument was not affected by the vibrations in an aeroplane. The only difficulty in using it in a strange station is that it is not known how closely to couple, and there is danger of burning out the indicating lamp.

Dr. Seibt is at present designing a switchboard type of this instrument. I have not found that low frequency fields affected this instrument. Radio frequency fields might. It must be remembered that there is no iron in the meter.

ROY A. WEAGANT: Might not a neighboring transmitting inductance affect the readings?

EMIL J. SIMON: I presume that would depend on the field intensity of the coil in question. The effect is probably small, because the internal field is concentrated, and the instrument shielded by an aluminum lining inside the case.

LEE DE FOREST: The stray field would be the same for both of the deflecting coils of the wave meter, and hence the effects would tend to compensate.

EMIL J. SIMON: The first U. S. patent application was filed in November, 1911, in the United States. The German application was filed six months previous to that.

A. E. KENNELLY (by letter): The application of the principle of the repulsion, exerted between an alternating current-carrying coil and a closed loop, to wave-length indication, by the differential action of two circuits of different impedances, is very ingenious, and must have required much experiment to develop. The great advantages of such a wave-length meter are its direct-reading property, and its swiftness of indication; whereby the judgment of a trained observer is rendered unnecessary.

In the case of a two-phase motor device, operated by phase-splitting branch circuits from single-phase mains, the purpose is to split the phases to as nearly 90° apart as possible, with the minimum difference between the two branch current strengths. In this wave-length measuring device, the purpose is to split the currents in the two branch circuits, and make the splitting ratio depend sensitively on the frequency in the main circuit. These branch circuits may be called ratio-splitting branch circuits.

THE HIGH POWER TELEFUNKEN RADIO STATION AT SAYVILLE, LONG ISLAND.

By Fritz Van Der Woude, Engineer of the Telefunken Company, and Alfred E. Seelig, Manager of the Atlantic Communication Company.

INTRODUCTORY.

As indicated by the title of the paper, we shall not concern ourselves in this article with any theory of the transmission of electric waves thru the ether, excepting where the occasion may specially demand. We shall confine ourselves to a description of a commercial radio station, recently built for long distance communication, and fairly representing a modern high power "wireless" station of the Telefunken type.

THE TOWER.

Near the South Shore of Long Island about half way between New York and Montauk Point, at the little town of Sayville, a piece of land covering about 100 acres was purchased. Here a steel tower 150 meters (about 500 feet) in height has been erected to support the antenna or aerial wire system, of the dimensions required for the radiation of the electrical energy. As this tower is quite interesting in its construction, and as the design has become closely identified with Telefunken radio stations, a short description will not be amiss.

Given the problem: To erect a steel tower of great height, whose one function shall simply be to support a few antenna wires at a minimum of material and cost.

The Sayville tower is of a type which the Telefunken Company has found to be the best answer to this problem, and one which is coming to be widely recognized as the most satisfactory solution. From Figure 1, it will be noted that instead of using the customary large polygonal support, sometimes referred to as the "Eiffel Tower Type," the base of the Sayville tower is brought to what is practically a point—or rather a ball and socket joint at

the bottom. The tower is therefore not self-supporting and depends entirely on its guys for maintaining it in its upright position. The joint at the base, however, gives great flexibility for resisting wind pressure. This pressure, of course, is the main load, and as the majority of radio stations are erected near the coast, wind velocities of 90 to 100 miles an hour must be reckoned with.

For towers more than about 120 meters in height it has in fact been found advisable to put another joint into the structure, and in the figure there will be observed such a second point, or node of vibration about three-quarters of the way up the tower. There is then a small super-tower which rests on the main lower structure. Both towers are triangular in section, the triangular shape resulting in a further saving of material as no cross bracing is required.

GUY ANCHORAGE AND INSULATION.

The insulation of the tower from ground is effected by a large glass insulator upon which rests the entire weight of the tower. Six large concrete and brick anchorages, one of which is shown in Figure 2, are distributed in two sets of three, spaced 120° apart on circles. The circles are of 235 feet (73 meters) and 430 feet (130 meters) radius, measured from the base of the tower. From each anchorage two guys, each consisting of linked steel rods run to the tower. Heavy glass insulators, which have been specially developed for this class of duty, electrically separate each guy from ground.

THE ANTENNAE AND COUNTERPOISE.

The main antenna is of the umbrella type, and consists of twelve wires radiating from the top of the tower in two segments of six wires, each segment covering an arc of about 120°.

The ends of each antenna wire are connected thru large bell-shaped insulators to steel wire ropes. These ropes are attached to the tower at the top and at the lower end to wooden poles about 30 feet (9 meters) high.

These wooden poles form a circle of approximately 2,300 feet (700 meters) diameter. Each antenna wire has only about one-third of the total length of the line from the top of the tower to the outer pole end. The long stretches of steel rope are

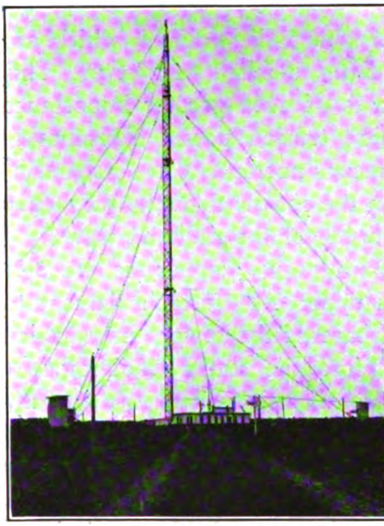

Figure 1

Figure 2

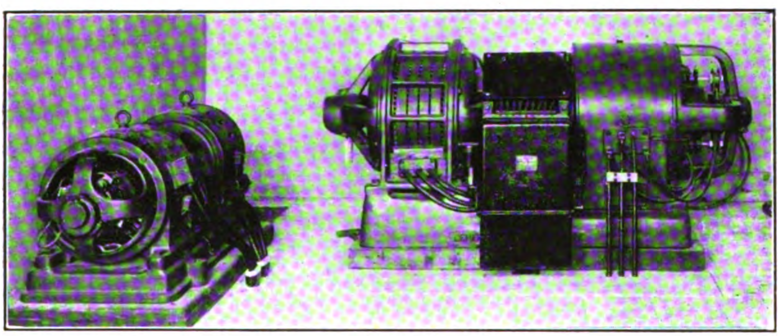

Figure 3

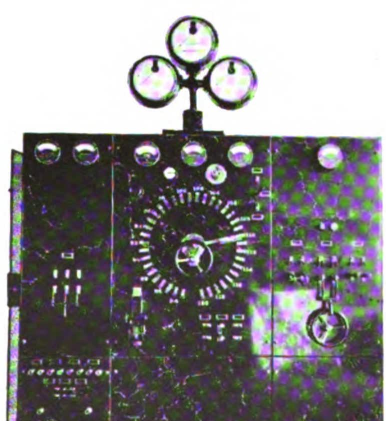

Figure 4

furthermore each subdivided into about six sections, which are joined thru porcelain insulators of the so-called "egg" type. This careful insulation of the antenna is of even greater importance than in the construction of a high tension power transmission line, for in the antenna leakage means not only a loss of considerable energy but also a change in the constants of the secondary or antenna circuit and in the damping of the radiated waves.

The antenna wires are of hard drawn copper, as are also the vertical leads connecting the upper end of each element to the main junction point near the base of the tower, from which point the antenna circuit is led into the station building. A special form of leading-in insulator is used where the antenna is brought thru the building wall.

The Sayville antenna has a capacity of approximately 10,000 cm., and a natural wave length of 1,800 meters.

As ground water is not conveniently available at all times, a counterpoise ground consisting of 56 wires, about 5 meters (16 feet) above the ground, radiating from a center and covering a complete circle was erected as the most satisfactory way of earthing the considerable amount of antenna current.

The antenna, the counterpoise, and the tower itself are each connected to earth thru a lightning switch provided with safety air gaps, for use in lightning storms or severe atmospheric disturbances.

We consider next the transmitting apparatus, and, beginning with the source of energy, pass thru the station.

THE POWER SOURCE.

The 2,300 volt lines of the Long Island Lighting Company, part of a three-phase 60 cycle system, comprising several power stations so joined as to make current available at all times with practical certainty, are tapped at the boundary of the station grounds and stepped down to 440 volts in a small transformer house. From this point the current is led thru an underground conduit into the station building, there operating the main motor-generator charging set. This set, which was made by the General Electric Company, is shown in Figure 3, to the right. It consists of an induction motor driving a 220-volt D. C. generator, which in turn charges a 600 ampere-hour storage battery. From this battery, the entire station apparatus draws its current.

Primarily the battery current is used to feed the two 500 cycle motor-generator sets. The high power set is driven by a 75 H. P. motor (Type 35 T. K.), and the smaller set has a motor of approximately 15 H. P. (Type 5 T. K.).* The smaller set has been used for regular ship and shore communication and as a reserve for the larger outfit, which it resembles closely in principle.

The switchboard in the generator room carries the end-cell switch for the storage battery and also the main feeder switches. The end-cell switch is shown in the upper portion of the central panel of the switchboard. (Figure 4.) A small control room is situated between the generator room and the transmitting room. It is shown in Figure 5. The partition walls of the control room are practically large windows, one on each side, so that the electrician in charge, who, from this point controls the entire apparatus, is enabled to see both the generating and transmitting equipment at all times.

Moreover, a system of small signal lamps as well as a speaking tube and call gong serve to maintain communication between the control and operating rooms.

TRANSMITTING EQUIPMENT.

The 60 K. V. A. 500 cycle single phase generator of the high power set feeds the main transformer, which raises the voltage to about 60,000. A simple hand and solenoid switching device placed between the generator and the transformer, when opened, disconnects the transformer and the entire transmitting apparatus without stopping the generator or reducing its field. Thus a single throw of this switch renders the entire transmitting system instantly accessible for any quick repairs or adjusments; without danger and with a minimum loss of time (which latter consideration may be of great importance in the midst of telegraph service).

The high voltage secondary of the transformer feeds the primary oscillating circuit thru a series choke coil which protects the transformer against excessive voltage due to surges.

The capacity of the primary circuit is made up of Leyden jars totalling 40,000 cm., that is, 0.044 μf. They are of the

*The term "T. K." is used by the Telefunken Company to designate actual kilowatts output, measured in the antenna. (Editor.)

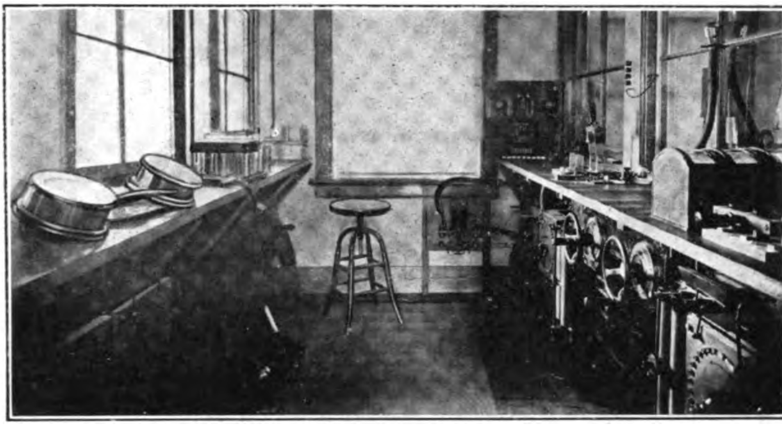

Figure 5

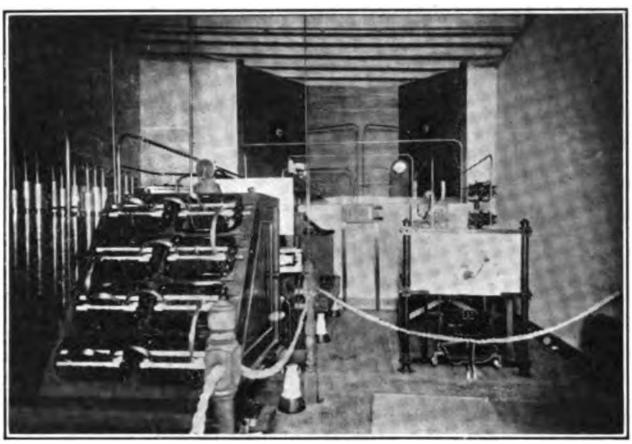

Figure 6

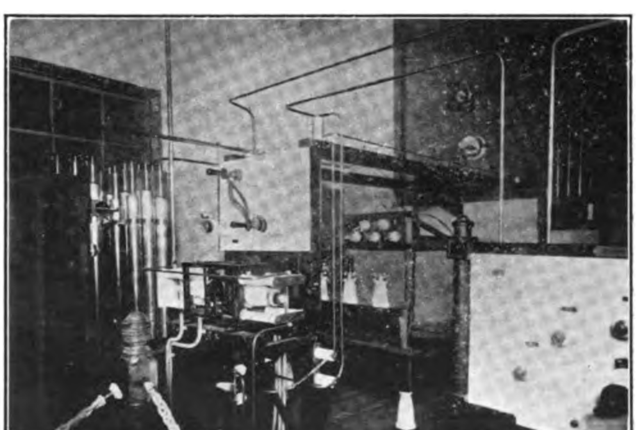

Figure 7

familiar Telefunken type, long and narrow, with tin foil coverings on glass 0.25 inch (0.6 cm.) thick.

The charged condenser in this circuit discharges itself thru a series of quenched spark gaps. Figure 6 shows the gaps and jars, as well as a smaller set to the right. The gaps are held in eight frames, arranged on a stand. A motor driven blower is provided for cooling the gaps. Each frame or set has 13 gaps, and the distance between plates of each gap is about 0.1 to 0.2 mm. The well-known quenching effect is thereby produced. Any frame can be easily disconnected and lifted out of the stand, and any plate quickly removed from its frame, whenever inspection or repair is desired. The plates now generally used are of the ribbed type, having four or five concentric circular ribs. This type of gap was found to give better results than the smooth type.

The gap completes our primary circuit, the inductance of which is coupled in part conductively and in part inductively with the inductance of the secondary or antenna circuit. These two circuits, primary and secondary, must of course be in resonance (or nearly so). As the clearness of the tone, as well as the efficiency of transfer of energy, depend on the value of the coupling, the closeness of coupling is made variable, one of the coils being moved nearer to or further away from the other. The adjustment of coupling is operated directly from the control room, where a hand wheel connects thru a system of sprockets, chains, and levers to the movable coils which are raised or lowered as desired.

RELAYS.

As the large amount of current in the transformer primary circuit cannot be broken directly by a telegraph key, a relay system must be provided.

At Sayville the current is controlled in steps by a system of three relays. The main relay, which breaks the full current, is installed in duplicate so that either one of those provided can be used by simply switching over to it. Each of the main relays has eight contacts, which are cooled by an ordinary electric fan. The 220 volt battery current is used thruout to energise the coils of the relays or other automatic control devices.

ANTENNA SWITCH.

One other piece of apparatus in the transmitting room is of considerable interest. This is the automatic antenna switch, operated by a small motor thru a solenoid switch, which in turn is controlled by a foot-pad contact in the operators' or receiving room. This switch is clearly shown in Figure 7. Each successive pressure of the operator's foot alternately switches the antenna from the receiving to the transmitting circuit and vica versa.

The same foot-pad alternately starts and stops the blower used for cooling the quenched spark gaps. In fact, the special conditions in Sayville require a very large number of functions to be performed at each switch-over. Thus in addition to what has just been outlined, the following must be provided for automatically:

1. When connected for receiving, it must be impossible for the operator to produce a spark discharge by closing his key—as he might easily do accidentally.

2. If the small set is working, the high power apparatus must be entirely disconnected (without necessarily stopping the generator) and vica versa.

3. The procedure in changing over from receiving to sending must be:

   (a) To disconnect the receiver.

   (b) To transfer the antenna connection from receiver to transmitter.

   (c) To close the relay contacts which are on the transformer supply circuit.

Then these steps must be reversed in switching from transmitting to receiving.

It is interesting to note that in order to perform all these functions successfully it was necessary to lay about a hundred wires between the two rooms.

OPERATING ROOM.

Separated from the rest of the station by sound-proof walls and double doors, and close to the land line telegraph room is the operating room. The telegraph room serves as the collecting

and distributing link for the traffic. In the operating room the receiving apparatus and the transmitting keys are conveniently mounted on tables arranged somewhat like large, flat-top desks. In order to avoid possible confusion of the operator, all the apparatus handled, such as keys, switches, levers, knobs and plugs have been painted either red or white according as they are part of the high power set or of the smaller set for the local ship and shore work. In this way the operator immediately knows whether he is handling the particular set desired even tho the various parts, as for example the transmitting keys of the two sets, may be very similar in appearance and placed side by side.

RECEIVING APPARATUS.

The receivers are of the familiar Telefunken upright type, serving for a wide range of wave lengths and therefore available for all classes of service. Diplex reception (of two simultaneous messages) is easily accomplished by a simple device which alternately connects first one and then the other receiver to the antenna at a high frequency; so that each receiver is in circuit three or four times during the lapse of time required for a Morse signal. With the aid of this device and careful tuning we have had no difficulty in receiving simultaneously three messages, one on a long wave length, and two on shorter waves. In fact, there is no reason why, with the equipment at Sayville, it should not be possible to receive six messages simultaneously, if proper care is taken in the choice of wave lengths and in tuning.

SOUND INTENSIFIER.

In the receiving room is another ingenious device that has been identified with the Telefunken system—namely the sound intensifier. It is visible in the background of Figure 9. Without going into the details of its construction, it will suffice to state that this apparatus depends on the principle of acoustic resonance. If the incoming signals have an acoustic pitch of one thousand cycles per second, there will be one thousand current impulses per second from the detector circuit acting on the membrane of a combined telephone receiver and microphone transmitter in the

Figure 8

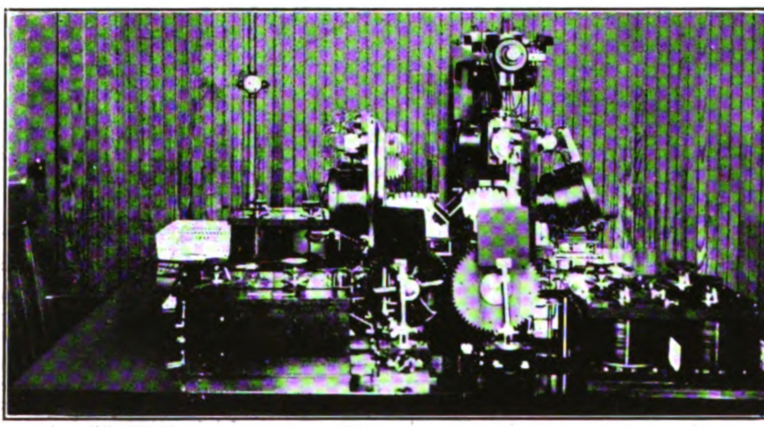

Figure 9

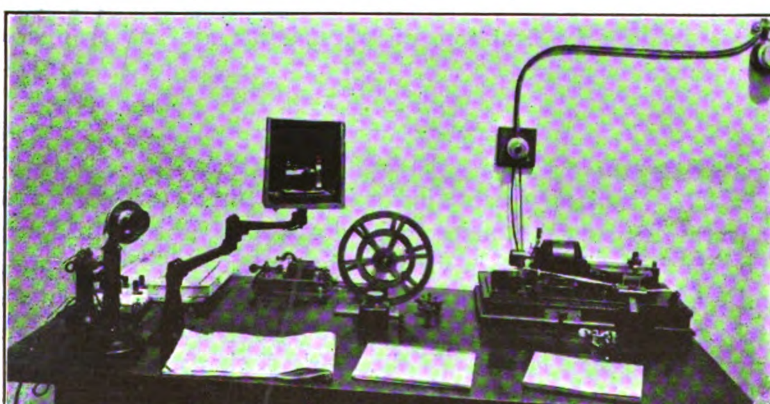

Figure 10

sound intensifier, thus producing in turn a thousand stronger impulses in another circuit. In the latter circuit is a local battery and another combined receiver and microphone. By stepping the current up thru a series of such circuits, a detector current of 10^{-7} or 10^{-8} ampere can be increased to one of 10^{-2} ampere or more. This not only produces sounds distinctly audible at considerable distances, but is capable of operating a Morse recorder in addition, if desirable.

Furthermore, as the sound intensifier responds only to impulses of a given frequency, thereby adding the effect of acoustic resonance to the radio frequency resonance of the receiving circuits, a very high degree of selectivity is obtained.

AUTOMATIC TRANSMISSION.

In connection with the transmission of long messages such as are encountered in press work, it is usually desirable to make the procedure as nearly automatic as possible. For this purpose Sayville is provided with an automatic transmitter consisting essentially of two pieces of apparatus:

1. The perforator ,in which a paper strip is unrolled at any desired speed and punctured by small holes; the separation between the holes representing either the dots or dashes produced by an ordinary telegraph key. Figure 10 gives a view of this apparatus.

2. The automatic transmitter. The punched tape is then run thru the automatic transmitter at any desired speed, the holes in paper controlling spring contacts, which open and close the transmitting circuit. Thus the rate of punching or preparing the tape, and the final rate of transmission are entirely independent of each other.

TONE CONTROLLER.

This simple device for indicating the number of spark discharges per second remains to be described. It is a miniature receiving circuit placed in the immediate proximity of the transmitter, and having as its discharge gap a small Geissler (helium) tube mounted on a rotating disc. This disc is driven by a small motor at constant speed. If the spark discharges have a constant frequency, and if their number is a simple multiple of the

revolutions per second of the disc, the rotating tube will appear as a stationary illuminated star. The number of sparks per second is equal to the product of the number of revolutions per second of the tube and the number of arms or rays in the star. Moreover, the width of each illuminated area, or broadness of each ray of the star, is proportional to the length of time during which the discharge voltage is equal to or above a certain value, and therefore is an indication of the amount of damping. Thus a highly antenna current will produce very thin rays.

DISTANCE RANGE.

Thoro tests of the range of the Sayville station have not yet been made. However, the daily press message, sent out each evening at about 9 o'clock has been distinctly received by vessels at Gibraltar and in the English Channel, i. e., at distances of 3,000 to 3,500 miles.

DISCUSSION.

CHARLES A. LE QUESNE, JR.: Do the vertical antenna leads consist of a vertical wire connected to each antenna wire?

A. E. SEELIG: Each antenna wire has a separate vertical lead. But an arrangement whereby each group of antenna wires was connected to one large vertical lead would not differ electrically to any great extent from that used.

HAROLD R. ZEAMANS: What was the maximum range attained by the station?

A. E. SEELIG: From Sayville to Gibraltar, that is, 3,200 miles.

JOHN L. HOGAN, JR.: Was that a day message?

A. E. SEELIG: This was press message sent at night.

JOHN L. HOGAN, JR.: May I ask how early the ball and socket joint at the base of the antenna was used by the Telefunken company?

A. E. SEELIG: Since 1904. More than twenty such towers are in use.

H. E. HALLBORG: What protective devices are used on the meters and generators?

A. E. SEELIG: Outside of the usual fuses, no protective devices are used. I may mention that all the wiring is in iron conduit.

FRANK FAY: What lightning protective device is used?

A. E. SEELIG: There is a large lightning switch provided. The receiver is also protected by a vacuum gap.

JOHN L. HOGAN, JR.: The diplex system used involves a rapid change from one set to another. Will there not be a click in the receiver each time the change is made due to the atmospheric charging of the antenna?

A. E. SEELIG: Such an effect is not found in practise. The musical tone is somewhat altered. It must be remembered that time of change is short while the time of contact is long with the arrangement used.

H. E. HALLBORG: Have you used the Einthoven galvanometer in receiving?

A. E. SEELIG: We do not send rapidly enough generally to justify the use of the galvanometer.

FRANK FAY: How many words per minute can you send with your automatic key?

A. E. SEELIG: The key is of such construction that we can send more rapidly than any operator could receive.

H. E. HALLBORG: Is the telephone receiver used, or the "tone amplifier" with recording device?

A. E. SEELIG: We have each of them in our equipment. Which is used depends on the type of service and the convenience of the operator.

H. E. HALLBORG: What is the capacity of each jar?

A. E. SEELIG: About 10,000 cm. (0.011 μf.) The jars are arranged in five groups, partly in series and partly in parallel.

EMIL J. SIMON: How many gaps are used in series, and how many kilowatts are drawn from the transformer?

A. E. SEELIG: There are 40 or 50 gaps in series. About 40 kilowatts are drawn by the transformer.

ROY A. WEAGANT: What is the antenna current?

A. E. SEELIG: About 120 amperes.

EMIL J. SIMON: Have you measured the current in the closed circuit?

A. E. SEELIG: No.

LESTER ISRAEL: What is the radiation resistance of the antenna?

A. E. SEELIG: At a wave length of 3,000 meters, it is about 3 ohms. We put 30 to 35 kilowatts into the antenna. The efficiency is 75 to 80 per cent from the generator to the antenna. The motor is one of 75 H. P., but is used at a constant load of 50 kilowatts.

EMIL J. SIMON: The efficiency of the motor-generator is 80 per cent?

A. E. SEELIG: That is its value. The generator is of the special inductor type developed at Nauen for this type of service.

H. E. HALLBORG: How is the proper leakage in the high tension transformer obtained?

A. E. SEELIG: It is a closed core transformer in series with which is a choke or inductance coil.

ROY A. WEAGANT: What are the open and closed circuit voltage of the generator:

A. E. SEELIG: They are 600 and 350 volts respectively.

EMIL J. SIMON: What is the generator current at full load?

A. E. SEELIG: The power factor is 0.8. Hence you can calculate the current from the voltage values and kilowatt output.

THE DAYLIGHT EFFECT IN RADIO TELEGRAPHY.

By A. E. KENNELLY.
(*Professor of Electrical Engineering, Harvard University.*)

It is now generally admitted that the range of radio-transmission of signals is materially influenced by solar radiation; not only in regard to false signals or "X's"; but also in regard to the attenuation of the transmitted electro-magnetic waves.

This attenuating influence of solar radiation on the transmitted waves ordinarily consists of (1) a nearly steady action during the daytime, together with (2) certain marked disturbances occurring near sunrise, or sunset, or both.

In regard to the first or steady effect, we may consider that during the day, whatever the weather may be; i. e., the conditions of wind, temperature, pressure, cloudiness or precipitation in the first few kilometers of air nearest to the ground surface, the sun's rays are steadily falling upon the upper layers of the air; where the air density is relatively very low. It is known from physical laboratory experiments, that ultra-violet light, passing thru attenuated air, ionises it; or decomposes electrically neutral air molecules into positive and negative constituents, the energy of decomposition being absorbed from the radiation. If the ultra-violet radiation is then withdrawn, these constitutents attract each other and recombine, perhaps converting the energy of recombinaion into heat energy or molecular oscillations. For a given intensity of received radiation of assigned wave-length in the ultra-violet region of the spectrum, we may suppose that there exists, in the final state, a certain corresponding number of free electrons per unit of air-volume. It is also reasonable to consider that after the ultra-violet rays in the sunlight have penetrated deeply into the air, they become: (1) scattered and diffusely reflected by the air-molecules, thereby giving us the blue color of the clear sky, and (2) absorbed in decomposition and ionisation of the air-molecules. Consequently, but little ultra-violet light from the sun reaches the ground, after passing thru the atmosphere. The solar spectrum at the ground, or ocean level, may be considered as terminating near to and only a little

beyond, the violet, when the sun's rays fall perpendicularly as at the tropical noon-day. At morning or evening, when the sun's rays pass aslant thru much greater distances of air before reaching the ground, the violet, and even the blue rays largely disappear, leaving a predominance of red in the light that remains, and thus producing the ruddy hues of dawn or evening landscapes.

If the upper regions of the atmosphere are appreciably ionised by full and sustained solar radiation during daylight hours, we may consider that these regions are thereby rendered partially conducting. That is to say, instead of being a perfect insulator, like free space or un-ionised air, ionised air has a certain small conductivity. This would involve a loss of energy in any electromagnetic waves traversing it, which, in turn, would involve additional attenuation of such waves. Moreover, if the ionisation-conductivity were not uniform but developed in clouds or patches, there would be scattering as well as absorption of energy.

It seems therefore possible to explain the weakening effect of broad sunlight upon radio-transmission signals by attributing conductivity, distributed either uniformly or non-uniformly thru the sunlit upper atmosphere, where the ultra-violet waves are likely to be more intense than in the region near the ground. We have no direct evidence, however, as to whether such ionisation-conductivity is quantitatively sufficient to account for the observed effects. It has been pointed out by Zenneck that the observed conductivity of air near the earth's surface for continuous current is far too small to account for the effects in question; but we have no experimental evidence as to what the conductivity may be at high atmospheric levels to alternating electric intensities.

If we assume, for simplicity, a tropical sun sending its rays perpendicularly down thru normally distributed air towards the earth, the degree of ionisation should be uniform over any surface situated at a uniform level. That is, the ultra-violet radiation would be most intense at a great height, and gradually weaken by absorption as it penetrated downwards. On the other hand, the number of air molecules per c.c.; i. e., the air density, would be relatively very small at a great height, and would increase exponentially with the downward penetration. In any one horizontal layer of air, the number of free ions might be assumed uniform.

Commencing, say, at zero, with sufficient height; it might increase to a maximum at a moderate height, and then dwindle down to a minimum near the earth's surface. If the sunlight ionisation, instead of varying gradually in this way terminated suddenly, so that, at some particular elevation a bounding surface formed with non-conducting air on one side, and conducting air on the other; then this boundary surface might be expected to develop strong reflecting properties, on the principle that wave disturbances are subject to reflection at surfaces of discontinuity. Thus clouds, or diffused masses of water vapor, reflect both sound and light. A travelling compression wave, or sound wave in air, reflects light. Any change in a medium for wave transmission, occurring at a surface, is known to set up a reflection. If the change is sudden and well-marked, so that the bounding surface is sharp, the reflection will be definite and powerful. If the change is gradual, and by easy transition; so that the bounding surface is not clearly defined, the reflection will be diffusely scattered and weak.

Consequently, if the ionisation of the air developed a sharp transition layer, or succession of layers, we might expect reflection to occur at and from such layers, with a lessening of attenuation; whereas, if the ionisation were gradually varying from layer to layer, with no clearly marked transition, there would be mere dissipation of energy by conduction or scattering without any gain by reflection, thereby increasing the attenuation.

It was pointed out by Dr. J. J. Thomson (1) that rarefied air at a pressure of 0.01 mm. of mercury in a glass chamber devoid of metallic electrodes, conducts electricity in the laboratory as well as an aqueous solution of sulfuric acid. At an elevation of about 70 km. (43.5 miles) above the sea level, and a uniform temperature of -60° C., such an air density may be expected to exist. If this free rarefied air conducts electricity in response to the feeble electric intensities of radio telegraphy, as well as it does in vacuum tubes to the more powerful intensities used in the laboratory; then, whether the sun is shining on this or not, we should expect a conductivity in it of the same order of magnitude as in ocean water. If such a conducting layer developed suddenly at a certain elevation, so that a definite bounding surface separated the conducting air above from non-conducting air be-

(1) J. J. Thomson, "Recent Researches in Electricity and Magnetism," 1893, page 101.

low, we should expect that surface to behave electrically like an inverted sea. Electro-magnetic waves, reaching this surface from below, would not penetrate it appreciably, but would be reflectively guided over it, as they are guided over the salt-water ocean below, and the waves would then spread over the surface of the globe in two dimensions only, like the growth of a stone-throw ripple in a pond, instead of in three dimensions, like the growth of a soap bubble. This would much reduce the natural three-dimensional attenuation, and increase the intensity of signals received at long distances. It has been suggested that some of the abnormally long signalling ranges occassionally reached at night may be due to the presence of such a reflecting layer [2]. If, on the other hand, the conducting layer exists, but is not sharply defined, the conductivity gradually increasing to a maximum as we approach from above or below, we might expect marked conductive dissipation with little or no reflection; so that long-distance signals might be weakened instead of strengthened, owing to the presence of the conducting layer.

Whatever the facts may be concerning the action of the air near the 70 km. level, it seems likely that, during full daylight, the solar ionisation cannot develop any sharp transition layers or reflecting boundaries in the atmosphere. That is, the daylight effect should tend to increase the attenuation of electromagnetic waves.

In order to form a definite conception of the relations between air-pressure and elevation above the sea, Figure 1 has been prepared on certain assumptions; namely, that the temperature of the air is uniformly -35° C. for the sea-level up to a height of 12 miles or 19.3 km. where the observed air-pressure is [3] 1⅞ inches (4.76 cm., or 0.0625 of normal sea level pressure). Up to this level, the "height of the homogeneous atmosphere" [4] is taken as 7 km. Above this level, the temperature has been assumed constant at -60° C. and the height of the homogeneous atmosphere uniform at 6.23 km. No correction has been made for changing chemical composition of the atmosphere at different elevations. [5] Thus premised, Figure 1 indicates that at the ele-

(2) "On the Elevation of the Electrically-Conducting Strata of the Earth's Atmosphere," by A. E. Kennelly, Electrical World and Engineer, Vol. 39, No. 11, March 15th, 1902, page 473.

(3) A. L. Rotch, "The Conquest of the Air," New York, 1909.

(4) J. Clerk Maxwell, "Theory of Heat," London, 1875.

(5) W J. Humphreys, "On the Physics of the Atmosphere," Jour. Franklin Inst., March, 1913.

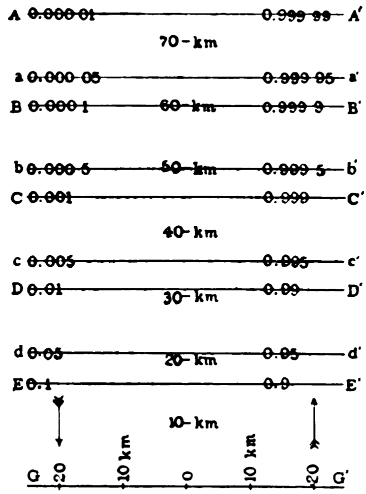

Figure 1. Air-Density and Penetration at Different Atmospheric Levels. Sun's Rays Vertical

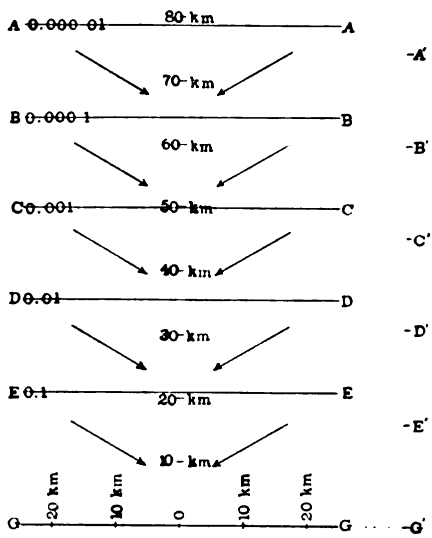

Figure 2. Penetration of Inclined Solar Rays at Different Atmospheric Levels

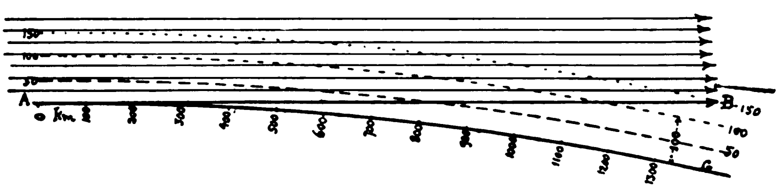

Figure 3. Diagram representing the Surface of the Globe with Three Atmospheric Levels 50, 100 and 150 Km. above the sea. Rays of Sunlight following Parallel Straight Lines are Tangential to the Globe at A and are Penetrating the Atmosphere above the Line AB which Marks the Bounding Surface between Light and Shadow. The Sun's Parallax and Atmospheric Refraction are Neglected.

vation bb′, 50 km. above the sea level GG′, the air pressure and density are 0.05 per cent of those on the sea, while 99.95% of the air lies below this level. Again, at an elevation of approximately 60 km., the density has fallen to 0.01%, and 99.99% of the total atmosphere lies beneath. In each 10 km., the air pressure is falling to one-fifth. A vertical sunbeam, reaching the level BB′, has passed thru 0.01% of the total atmosphere. The successive levels AA′, BB′, are lines of equal penetration, and there should be equal intensities of ionisation over each such level; but there should not be any layer of sudden transition.

Figure 2 represents the same atmosphere conditions as in Figure 1; except that the sun's rays are supposed to be entering the atmosphere at an inclination of 60° with the zenith, as indicated by the arrows on either side. Along these inclined paths, the sunbeam will encounter approximately twice as much air between any two given elevations as in Figure 1. Consequently, at the 50 km. elevation, the sunbeams have traversed 0.1% of a vertical atmosphere, instead of only 0.05%. The levels AA′, BB′, CC′ of 0.001%, 0.01% and 0.1% respectively are all raised about 5 km. with respect to those on Figure 1. Otherwise, there is very little change between the conditions of penetration by rays from an overhead sun at the equator, and those from the sun at either 8 A. M. or 4 P. M. There should be no sudden transition layer or surface of discontinuity in ionisation, in either case.

When, however, the sun's rays are striking tangentially over a place on the globe as in Figure 3, there tends to be a transition along the line AB, between air in the shadow and air in the sunshine. If the condition represented is that of sunrise, then the air still in shadow is presumably air that has become neutralized during night, with a relatively low conductivity. The illuminated air on the other hand is rapidly becoming ionised and more conductive. While, therefore, we cannot expect the moving shadow plane to be a sharply defined surface separating ionised from neutral air, we might reasonably expect a roughly defined bounding surface, such as might produce some diffuse reflection of electromagnetic waves. No attempt is made to indicate the lines of equal penetration or ionisation, owing to the complexity of the actions. It is known that there is a very appreciable refraction of the beams of light. We should also expect absorption to take place at different elevations, and inoisation to increase to some extent with time. The shadow boundary AB steadily advances

toward G in the diagram. All that can be asserted definitely is that there is a greater probability of a transition layer, or partially reflecting layer, being formed between sunshine and shadow at sunrise and sunset, than at any place in the sunlit region of daylight. The ionised layer boundary cannot coincide with the shadow boundary AB, but will lag behind it, and will rise more nearly vertically, owing to the effects of atmospheric absorption, and of building up with time. We may call this hypothetical transition layer, or boundary between daylight and darkness, the "shadow wall" accompanying sunrise or sunset.

In Figure 4 we have a stereographic projection of part of the northern hemisphere. The lines of longitude at hourly intervals may be considered as representing the positions occupied by either the sunrise or sunset shadow walls, at successive hourly intervals at the equinox, when the sun appears on the equator. The shadow, considered as an imperfect electromagnetic mirror, may only extend upwards say from the 30 km. level to the 130 km. level; or may only occupy a height of say 100 km. in all; but, if it exists, it extends northwards and southwards for thousands of kilometers. In summer, the wall would slant from S. E. to N. W., and in winter from S. W. to N. E., across the globe.

If the boundary surface between day and night; or the shadow wall, possesses roughly reflecting or scattering influence on electromagnetic waves, we should expect to find the following series of phenomena in relation to two stations east and west, on or near the same parallel of latitude, as indicated in Figure 5; where the observer is supposed to be at the earth's south pole looking at the rotating pole beneath him.

(1) When both stations are in full shadow, as at 20, 20′: 21, 21′; 22, 22′; 23, 23′; 0, 0′: 1, 1′; 2, 2′; 3, 3′; 4, 4′; the signals exchanged should be normal, in the absence of thunderstorms or meteorological disturbances.

(2) When, shortly before dawn, at the eastern station, the shadow wall gets behind that station, it should act as a partial reflector to that station, and intensify the signals.

(3) When the shadow wall advances to a point between the stations, as at 6, 6′, the wall should act as a partial barrier between them and weaken the signals.

(4) When the wall reaches a point a little beyond the western station, as at 7, 7′, it should act as a temporary reflector to the latter, and temporarily strengthen the signals.

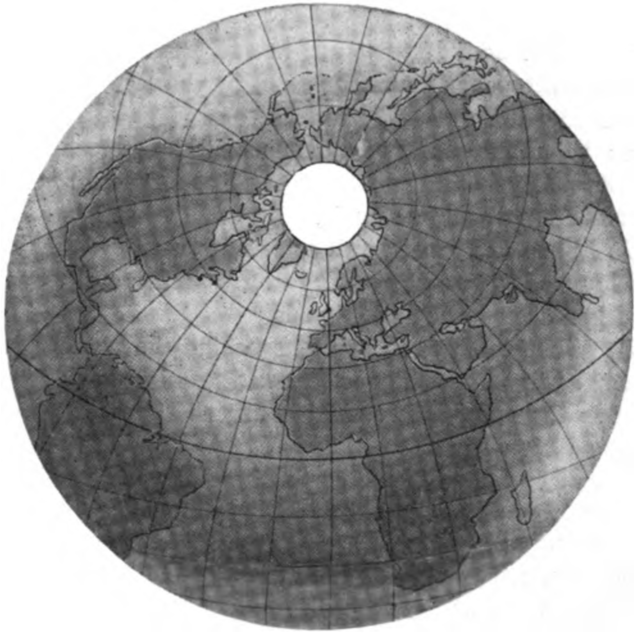

Figure 4. Projection of the Globe

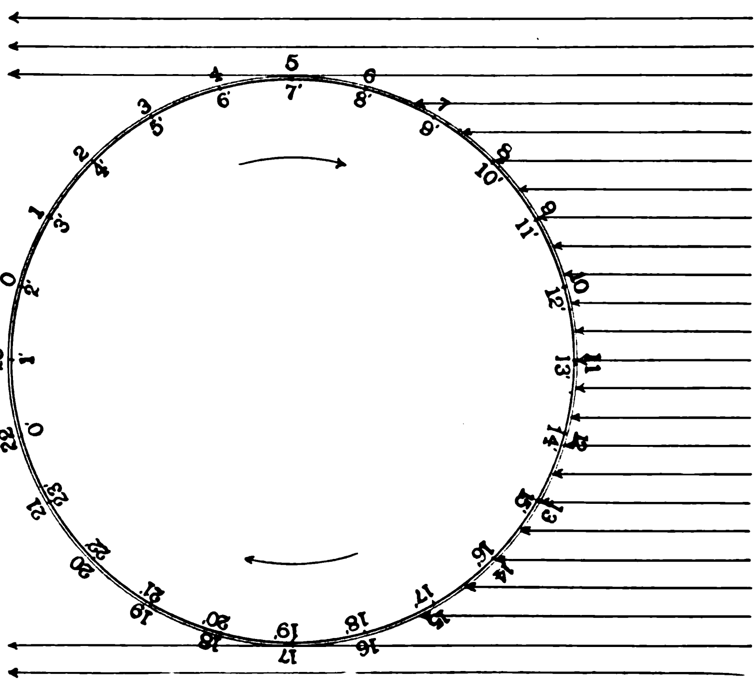

Figure 5. Rotation of the Earth with Regard to Sunlight as Viewed from South Pole.

(5) When both stations are in full sunlight, their signals are subjected to daylight attenuation, by diffused conduction in the upper air.

(6) When the sunset wall gets behind the eastern station, as at 17, 17′, the wall will temporarily serve as a reflector behind the latter, and strengthen the signals.

(7) When the sunset wall intervenes between the stations, the wall will act as an intercepting barrier, reflecting waves back, and markedly weakening the signals.

(8) When the sunset wall gets behind the western station, there will again be a temporary increase of signals by reflection. After this the conditions should approach those of permanent shadow, or night time.

In one revolution of the earth, therefore, we should expect to find maximum strength on full night shadow, a lowered strength in full daylight, and a marked weakening of the signals, with the wall between the stations, either at mid-sunrise, or at mid-sunset. [6] Each of these dips in the strength of signals should be both preceded and followed by a brief interval of stronger signals, due to partial reflection, in the same way as a rough or imperfect sheet reflector behind a lamp intensifies its rays.

On the other hand stations on the same parallel of longitude should have no dip on signals on the equinoxes; but should have a dip at sunrise and sunset with the sun near the solstice. (December and June.)

Stations north and south might expect a longer signaling range than those east and west owing to the aid of partial reflections along the shadow wall.

We may now compare the foregoing deductions with recorded observations. Figure 6 is taken from observations by Mr. G. W. Pickard in 1909, [7] as published in Figure 97 of Prof. G. W. Pierce's book on Wireless Telegraphy. It will be observed that there is a marked dip in the intensity of signals received at Amesbury, near Boston, Massachusetts, when sunrise was about midway between Amesbury and the sending station at Glace Bay, Nova Scotia. Both of these stations are indicated in Figure 4 by

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(6) This provisional theory of the sunrise and sunset dips was first put forward by the writer at the Radio-Telegraphic Discussion of the Dundee meeting of the British Association, September, 1912.

(7) "Principles of Wireless Telegraphy," G. W. Pierce, New York, 1910, page 135.

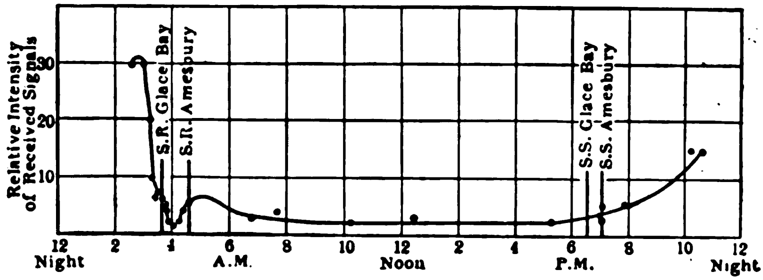

Fig. 6. Observations taken by Mr. Pickard on the relative intensity of signals received at different hours of day and night.

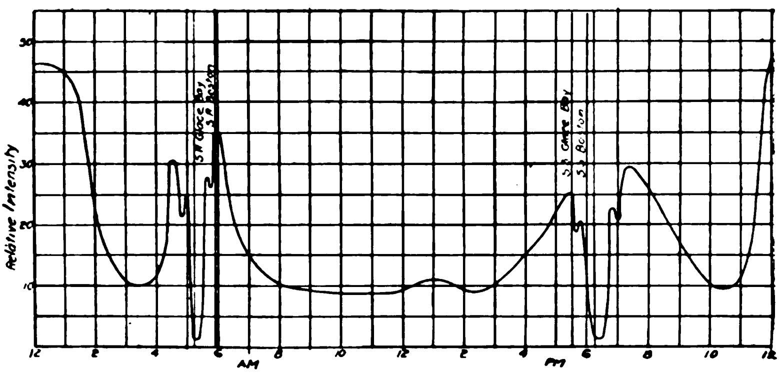

Fig. 7. General average of all curves taken at Somerville and Revere March, 1911.

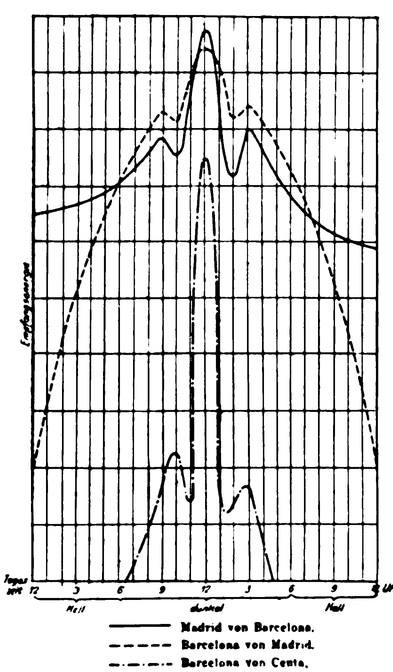

Figure 8

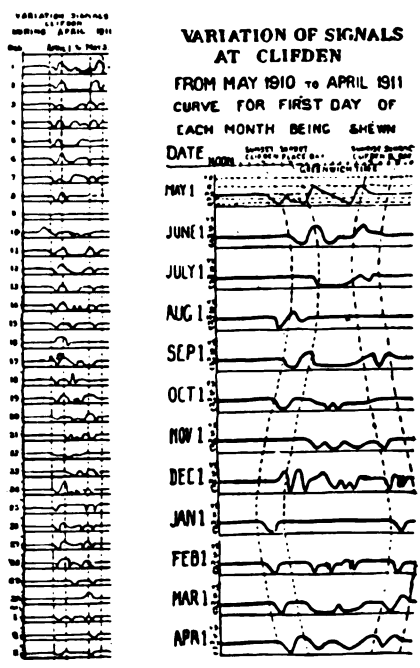

Figure 9

black dots. There is a reinforcement after the dip, and perhaps also before it. On the other hand, at sunset, no dip is indicated, such as the foregoing theory would indicate.

Figure 7 is taken from observations by Messrs. Dolbear and Proctor [8] in March, 1911. Here Glace Bay is again the sending station; while there were two independent receiving stations, one at Somerville, and the other at Revere; both suburbs of Boston. The diagram, taken from the published article, purports to give the general average of all the observations made at both receiving stations, at a period of the year near the vernal equinox. It will be seen that there is a dip both at mid-sunrise and at mid-sunset, with reinforcements both before and after each dip. There is a nocturnal maximum and a daylight reduction. The results set forth in this particular diagram are in closer accordance with the hypothesis here put forward than almost any others, but no explanation was offered or theory advanced in the article, by its writers.

Figure 8 gives some observations reported from Madrid, and Barcelona in Spain, and also Ceuta, in Africa, nearly opposite to Gibraltar. Here the nocturnal maximum is very short. There is a sunrise and sunset dip, with reinforcement before and after.

Figure 9 gives a published series of observations reported from Clifden, Ireland, as to the diurnal strength of signals from Glace Bay, N. S. One column gives the diurnal chart for each day in April, 1911. Here the agreement with the theory is not so good. There is usually, but not always, a dip at mid-sunrise and mid-sunset. Sometimes the sunrise dip is missing, and sometimes the sunset dip. There is often a reinforcement in the signals before and after a dip; but in many instances such a reinforcement is not indicated.

The records appear to have been made in all cases by shunting the receiving telephone with non-inductive resistance down to the point of inaudibility. The strength of signals is then estimated from the conductance of the limiting shunt.

It appears, therefore, that there is sufficient warrant from the observations at hand in giving the theory here suggested for the sunset and sunrise dips further consideration. It is not claimed

(8) The Effects of Sunlight on the Transmission of Wireless Signals, by B. L. Dolbear and J. A. Proctor, Electrical World, N. Y., Vol. 58, No. 6, Aug. 5th, 1911, pages 321-323.

that the theory is more than a working hypothesis. It is a suggestion to be judged according to such further evidence as may be accumulated. The information at present available is insufficient to demonstrate any theory of the subject. The records indicate that the phenomena are complicated. It may be that there are meteorological disturbances of the upper air which superpose their effects upon a normal diurnal regime. Our knowledge of the atmosphere by direct exploration with manned balloons is limited to an elevation of about 11 km. By means of small "sounding balloons," carrying up self-registering instruments, we obtain occasional records of pressure and temperature up to about 30 km. Above this level, we have no immediate prospect of securing observations by direct exploration. Nevertheless, the twilight limit of atmosphere, or the height at which the air can reflect twilight, is taken at 75 km. Auroral discharges in air, and shooting stars in air, are located much higher.

It would seem as tho information concerning the upper atmosphere might be obtainable thru concerted observations of radio telegraphic signals. The apparatus required for this purpose is simple and inexpensive. It would consist essentially of a receiving aerial, a detector and receiving instruments, with some means of estimating the strength of received signals at different hours of the day and night. The radio telegraphic amateurs might here render valuable service, by co-ordinating their efforts in observing signals regularly. There is no part of the world where an amateur, who is in the range of some large fixed station might not help in this work. It is to be expected that the accumulation of amateur observations in this way would be useful not only to radio telegraphy, but also to the general sciences of meteorology and solar physics. THE INSTITUTE OF RADIO ENGINEERS might aid greatly in this work, by enlisting observers using printed instructions for executing observations, collecting, collating, condensing and publishing the results. Fifty observing stations, grouped at various azimuths and distances around a single powerful radio sending station, would be none too many for the proper checking up of the measurements. In this way, the energy and enthusiasm of any number of amateur radio-telegraphists could be utilized to advantage. Once the system was inaugurated, the large sending station would

probably be willing to assist by furnishing a continuous record of the current and voltage in their sending antenna.

SUMMARY: The influence of solar radiation on radio transmission is discussed. The changes of intensity of signals near sunrise and sunset are explained by reflecting effects which may be expected at the boundary surface or "shadow wall" between darkness (air of small conductivity) and illumination (ionised air of marked conductivity). The theory and recorded observations are found to be in reasonable agreement.

It is proposed that amateur radio telegraphists shall cooperate with THE INSTITUTE OF RADIO ENGINEERS in gathering data on the strength of received signals under various conditions.

DISCUSSION.

DR. J. A. FLEMING (by letter): The subject of Dr. Kennelly's Paper is one which continues to attract great attention from radio-telegraphists on account of its practical importance. Unfortunately, it is a large scale effect, and one not very amenable to laboratory experiments. Much, however, may be done by systematic observations of stray atmospheric waves and on the signals sent out from large stations.

At the British Association Meeting last year, at Dundee, I had the honor of opening a discussion on "Some of the Unsolved Problems of Radiotelegraphy," and at the conclusion of that paper made the suggestion that the British Association should appoint a Radio Telegraphic Committee to bring conjoint investigation to bear on some of these questions. That suggestion was adopted, and the Committee appointed with Sir Oliver Lodge as Chairman. The Committee has already held one meeting. I hope that, as one result, an attempt will be made to organize systematic observations on the number and intensity of atmospheric stray waves during the hours of day and night, and over large areas. This is a work in which we may enlist the assistance of amateurs, and it has the advantage that it is entirely receptive work, and involves no production of waves or disturbance of the ether. Much of the amateur work hitherto done has been merely playing at radio-telegraphy, and has had no other result except to disturb commercial work.

In order that we may test our theories of atmospheric action on long electric waves, we require the prolonged collection of statistics as to the variation of the atmospheric stray signals over long distances. This work would be greatly assisted by the establishment of numerous stations sending out time and weather signals over large areas. Such a system will come into operation to some extent on July 1st, 1913, when time and weather signals will be sent out from many radio-telegraphic stations at regularly appointed hours. If these signals are made with constant antenna currents, they will afford the means of testing the transparency of the atmosphere to electric waves over large distances, and assigning to the received waves a numerical value as regards intensity. I am now engaged in working out an improved method of measuring the intensity of the signals as received on any given antenna, which, I think, will be an improvement on the shunted telephone method now used. If we suppose that intelligible signals could be made at any place without intermission day or night, and all the year round, and of exactly the same strength at the transmitter, they would be received 1,000 miles away with different strengths at different times of the day and year and probably of a cycle of years. Before we can find an adequate theory to explain this variation, we must tabulate the variation and express it by curves like the variation of terrestrial magnetic force or the frequency of sun spots.

There is an increasing body of evidence to connect the variation with atmospheric ionisation. One of the most useful inventions, in this connection, would be some automatic device for registering atmospheric ionisation, which could be sent up to various heights in an unmanned balloon and then recovered again like a self-registering barograph or thermometer. If we could in this way determine the ionisation at various heights and various times, we should lay a firm basis for a true theory. As yet we know very little with absolute certainty about the ionisation in the atmospheric region which begins at about 7 miles elevation, and is variously called the *stratosphere* or *isothermal* region. In it the temperature gradient is constant, or nearly so, in an upward direction. If the ionisation is to be measured by atmospheric conductivity, then we need, above all, some solid information on this subject.

I suggest, therefore, that THE INSTITUTE OF RADIO ENGINEERS (in the United States particularly) should take

up this question experimentally, and should endeavour to lay a firm foundation for a theory of long-distance radio-telegraphy by accumulating information on the important question of the electric conductivity and ionisation of our atmosphere at various heights above the earth's surface. Something might be done by the use of a Gerdieu's ionimeter in dirigible balloons or in aeroplanes. University College, London; June 24th, 1913.

ALFRED N. GOLDSMITH: There are a number of effects in the transmission and reception of signals by radio communication which are as yet only partly explained. Those most closely related to the present paper may be classified as follows:

(1) The superiority of transmission over water as compared with transmission over land.

(2) The superiority (under certain conditions) of transmission on high wave lengths as compared with transmission on short wave lengths.

(3) The clinging of electromagnetic waves to the earth's surface, in spite of the considerable curvature of the globe.

(4) The superiority of transmission by night as compared with transmission by day.

(5) The "daylight effect," or change in intensity of received signals at or near sunrise and sunset.

Before classifying the proposed explanations of these effects, we shall consider briefly the bibliography of the propagation of electro-magnetic waves thru space and over the surfaces of more or less perfect conductors. The classical papers of Hertz and his immediate followers have rendered wave transmission thru space alone thoroly clear. The next problem in order of complexity is the radiation from a Hertzian doublet (dumb-bell oscillator) thru the equatorial plane of which a perfect conductor of indefinite extent stretches. Such a plane conductor may be regarded as a first approximation to the "ground" of a radiotelegraphic station.

M. Abraham, in 1901, gave the mathematical solution of this case [1] and its physical interpretation. Considering the wave at a distance from the oscillator, he found that

(a) The lines of electric force were perpendicular to the conducting plane, the lines of magnetic force parallel to it.

(b) The electric and magnetic field intensities are in phase.

It will be noted that these conditions apply only when the equatorial plane is a *perfect* conductor. This is nearly the case for sea water, but not at all for dry land. J. Zenneck considered this problem in detail for the case of an imperfect conducting plane. [2] For the case of the partial conductor he found

(a) The lines of magnetic force are parallel to the plane, the lines of electric force are inclined in the direction of motion of the wave.

(b) The electric force has a horizontal component which is nearly in phase with the magnetic force.

(c) The vertical component of the electric force and the horizontal component of the electric force are out of phase with each other.

There is a resultant rotary electric field at the surface of the plane.

Zenneck gives the following values for the field forces at a distance from an antenna of height h, of form factor α, in which flows a current I_m, and from which are radiated waves of length λ:

$$\text{Electric Force} = 4\,\pi\,\frac{\alpha\,h}{\lambda}\,I_m\,\frac{\varepsilon^{-\beta s}}{s}\,3.(10)^{10} \quad \text{C. G. S. Units} \quad (1)$$

$$\text{Magnetic Force} = 4\,\pi\,\frac{\alpha\,h}{\lambda}\,I_m\,\frac{\varepsilon^{-\beta s}}{s} \quad (2)$$

where β is a constant. It will be seen that the values of these forces are dependant on the wave length.

The effects of the conductivity of the ground plane and of underground water or rock have been exhaustively studied by F. Hack [3] and P. Epstein [4] has given figures for the electric lines of force of actual waves (of length of 2,000 meters) passing over soil of high conductivity, and at considerable distances from the antenna.

Of particular interest in these latter papers is the proof of the existence of a varying horizontal component of the electric force on the wave front. Such electric forces exist on wires along which guided or surface electric waves are passing, and the question naturally arises whether we are not dealing with surface waves if the case of terrestrial radio transmission. Among the earlier investigators of such guided waves and of their probable

part in radio telegraphy are A. Blondel [5], E. Lecher [6], and K. Uller [7], [8]. However, it remained for A. Sommerfeld in 1909 [9] to give a broad theoretical treatment of the spread of electromagnetic waves over a partially conducting sheet placed, as before, in the equatorial plane of the oscillator; the sheet being plane. Because of their importance, Sommerfeld's explanations and his conclusions will be considered in some detail.

He first discusses the fundamental energy distinction between space and surface waves. Space waves, such as electromagnetic (Hertzian) waves and sound waves, spread three-dimensionally. Their energy (per unit area of wave front) is therefore proportional to the inverse square of the distance from the source. Surface waves, such as ripples on water, electric waves on wires, and elastic waves of surface distortion in solids, decay according to a different law of energy diminution. Thus, for waves spreading circularly over water, and neglecting dissipative absorption in the medium, the energy varies inversely with the distance; not as the inverse square.

Sommerfeld defines a quantity U in his paper as follows:*

$$U^2 = \frac{K \mu n^2 + j \mu \sigma n}{c^2} \tag{3}$$

where K is the dielectric constant, μ is the permeability,

σ is the conductivity, j is $\sqrt{-1}$,

n is the frequency, c is the velocity of light.

From U_1 and U_2, the values of U for air and the conducting sheet respectively, he builds up a new quantity ρ, which he calls the "numerical distance." If S is the actual distance, ρ is defined by the following equation:

$$\rho = \frac{U_1^4}{U_2^4} \cdot \frac{U_1^2 - U_2^2}{U_1^2} \cdot \frac{U_1 s}{2} \tag{4}$$

Sommerfeld sets up the partial differential equation for his problem, introduces the necessary boundary conditions, and, after a series of elaborate analytical transformations, arrives at the following value for Π, the vector potential at any point:

$$\Pi = P + Q_1 + Q_2 \tag{5}$$

Herein P represents that portion of Π. which is due to a true surface wave, and Q_1 and Q_2 represent space waves in the two

*The quantity U is Sommerfeld's "k". The notation here employed is, where possible, that recommended by the Standardisation Committee of THE INSTITUTE OF RADIO ENGINEERS.

media (that is, in space, and in the partially conducting sheet).

The relative importance of the space and surface waves is found to be determined by the value of ρ. The value of ρ for sea water is 0.03, for pure water 30, for wet earth 6.5, and for dry soil 300 (for a wave length of 2,000 meters at a distance of 2,500 km.) It is seen that the numerical distance increases with the real distance, diminishes with increased wave length, and is less for equal distances over sea water than over land. Furthermore, Sommerfeld's analysis shows that the assumption of perfect conductivity of the ground is allowable only for short distances over sea water. The distance from the antenna at which the surface or space waves predominate is determined as follows:

(a) For small values of the numerical distance, the space waves predominate.

(b) For larger values of the numerical distance, surface waves predominate.

(c) For very large values of the numerical distance, the space waves may again predominate, but this last effect may be neutralized by the effect of the curvature of the earth, and is probably not important in practise.

The surface wave is the more desirable one for long distance reception because it decreases far more slowly with distance than the space wave. The numerical distance should therefore be kept small so that the surface waves soon predominate. This may be secured by the following means:

(a) Increasing the wave length.

(b) Increasing the conductivity of the ground.

(c). Increasing the dielectric constant of the ground.

These conclusions are well borne out in practise. Sommerfeld has also suggested that daylight absorption is due to higher conductivity of the air causing an increase in U_1, and thereby increasing the numerical distance. In support of this, he mentions that Ebert found that the conductivity of air at a height of 2,500 meters was 23 times greater than at the earth's surface. It is, however, the opinion of other investigators, notably Messrs. Zenneck and Pierce, that the ionisation of the air due to sunlight is entirely insufficient to account for the magnitude of the observed effects.

Sommerfeld's work has been carried further by H. March (10), H. Poincaré (11), (12), J. W. Nicholson (13), and W. V. Rybczynski (14). The practical conclusions to be drawn from all these

papers relate to the superiority of long wave transmission, and transmission over water. A further aspect of the problem is considered in them, namely the effect of the curvature of the conducting sheet or ground.

It will be remembered that Sommerfeld regarded this conducting sheet as plane, and it would certainly seem that the transmission of electromagnetic waves over an earth quadrant despite the curvature requires explanation. The papers just cited supply this explanation. They show that

(a) For a spherical, perfectly conducting ground, the energy of the wave decreases not as $\frac{1}{S}$ but as $\frac{1}{S}\sqrt{\frac{\theta}{\operatorname{Sin}\theta}}$ (6)

where θ is the angular separation of the points considered measured along a great circle of the earth (neglecting "scattering").

It follows, therefore, that the amplitude at any distance from the antenna will be greater than for a plane ground, and may even rise to considerable values at the antipodes. There is, however, a second consideration, namely, the failure of the energy to fully follow the earth's surface and its consequent re-radiation or "scattering." It results in the introduction of what I shall call the "concentration factor."*

The theory shows that for a spherical, perfectly conducting ground

(b) The energy of the wave, taking account of scattering or re-radiation of energy from the surface wave, is obtained by multiplying the value obtained under statement (a) above by the concentration factor:

$$\varepsilon^{-0.0019\sqrt[3]{\frac{S}{\lambda}}} \qquad (7)$$

where λ is the wave length (wave length and distance expressed in kilometers).

The calculated values of the concentration factor for a distance of 5,000 km. is 0.0025 for a wave length of 4,000 meters and 0.0086 for a wave length of 8,000 meters. The advantage of using long waves is again apparent.

The expression for the energy of the wave obtained according to statement (b) above is in reasonable agreement with the results obtained experimentally by Dr. Louis W. Austin [15].

*Usually called "Zerstreuungs Faktor," or "scattering factor."

A complete theory of propagation of electromagnetic waves on a sphere of material of *finite* conductivity has not yet been developed.

There is another source of loss of energy in transmission which is generally not considered, namely, the loss thru ground currents in the immediate neighbourhood of the antenna. Inasmuch as considerable absorption of energy undoubtedly takes place in this vicinity, some interest is attached to conclusions drawn by Brylinski [16] relative to the resistance to alternating current of a homogeneous plane conductor of indefinite extent, the current flow being parallel to the plane. (It has been shown experimentally that this is very nearly the case for actual transmitting stations). Brylinski shows that the resistance increases with the specific resistance of the material, with the frequency of the current, and with the damping of the current. Remembering that the nearest approach to an ideal Hertzian doublet, radiating without loss in the surrounding medium would be attained by having a perfect conducting mass extending thru the equatorial plane of the doublet, and that this implies that the ground resistance to an infinite distance is zero, we find that long distance transmission is best attained by the use of sea water grounds, long waves, and continuous radiation of energy. The first two of these conclusions are in accord with the facts, the third point is one requiring further investigation.

Returning to the effect of atmospheric ionisation on transmission, an ingenious explanation of daylight absorption has been suggested by J. A. Fleming [17], [18]. If the upper layers of the atmosphere are strongly ionised by sunlight, the ions produced may act as nuclei for the condensation of water vapor. As a result of the presence of the water drops, and the high dielectric constant of water (namely, 80) the upper layers of air have a higher dielectric constant after exposure to sunlight. Fleming experimentally found that the dielectric constant of steam-laden air varied between 1.004 and 1.026. Therefore the electric waves will travel more slowly in the upper layers of air than in the lower, and the wave front will be tilted backward relative to the direction of transmission. In consequence of this tilting back of the wave surface, the entire wave may pass directly over the receiving station. The effect is quite similar to diminishing the concentration factor. On Fleming's hypothesis, daylight absorption should be least for

(a) Long waves, because their concentration factor is larger, that is, they follow the earth more closely. In fact, in

(b) Any conditions where surface waves predominate, e. g., over water.

The increased dielectric constant of moisture laden air may account in part for certain well-defined interference effects, as explained by Dr. Lee de Forest [19].

Dr. W. H. Eccles [20] gives a theory of wave propagation in ionised air which, under certain conditions, leads to conclusions directly conflicting with those of Fleming. Thus, according to Eccles, as a result of ionisation of the upper layers of the atmosphere, the wave front may be tilted forward so as to follow the earth's surface more closely; in fact, ionisation might thus assist long distance transmission. There are, then, two opposing effects, the relative preponderance of which determines whether the wave front is tilted forward or backward.

(a) It is tilted backward if, because of ionisation there is a deposition of water on the ionic nuclei, with a consequent increase in the dielectric constant.

(b) It is tilted forward if the presence of ions of molecular dimensions increases the velocity of the waves.

Further experiment on these points is highly desirable.

It will, however, be noted, that regardless of whether effect (a) or (b) predominates, Professor Kennelly's explanation of the sunrise and sunset effects as due to reflection at the boundary surface between ionised and un-ionised air still holds. Effect (a) would provide a more nearly complete reflection.

It has been further suggested that the antenna may be actually discharged by ultra-violet light in sunlight falling on it (Hallwachs effect). This, and other interesting points relative to the influence of atmospheric conditions on transmission and reception are fully treated in a recent publication by M. Dieckmann [21]. The attention of the experimenter in this field is directed particularly to Professor Fleming's valuable paper before the British Association [22] and to the chapter on electric wave transmission in Professor Zenneck's "Leitfaden der Drahtlosen Telegraphie" [23] to both of which sources I desire to acknowledge my indebtedness for suggesting some of the material given in this discussion.

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Dr. L. W. AUSTIN (by letter): An idea, held some time ago, that the difference between the strength of signals by day and those by night was due to the ionization of the air around the sending antenna, caused by the ultra-violet light from the sun, has been entirely abandoned.

An alternative explanation, that the increased strength of signals at night was due to diminished conductivity in the upper conducting layers of the atmosphere at night, seems improbable in view of data in the possession of the U. S. Navy Department.

This data shows that: (1) In certain regions and at certain wave lengths the ground absorption is greater than over equal stretches of salt water in the ratio of as much as twenty to one. Yet signals are sometimes received in such regions at night with the same strength as if there were no absorption at all. The sunlight can hardly affect ground absorption. (2) When working with sustained waves from arc radio-telegraph sets, the strength of signals may be great on certain wave lengths and very weak at other slightly different wave lengths. Thus a change of two or three per cent. in wave length produces enormous changes in intensity of signals. The probable explanation of this effect is, in accordance with Dr. de Forest's suggestion, (Proc. Inst. Radio Engineers, Vol. I, No. 1, page 37, 1913) that interference between a set of waves travelling along the earth and another set which have been reflected from conducting layers of the upper atmosphere takes place. There is no doubt as to the existence of this effect. The probable reasons for the failure to observe it with spark sets is partly because of the greater changes of wave lengths employed with such apparatus, and partly because the shorteness of the wave trains does not permit the direct and reflected waves to overlap and interfere for any considerable number of wave lengths.

The most probable explanation of the increased strength of night signals is to be found in an increase of energy received

by the reflection of the waves from the upper layers of the atmosphere rather than in any diminution of absorption. This implies a stratified structure of an ionized atmosphere at night, this structure being broken up by convection currents of air and changing illumination during the day.

Observations at Brant Rock and at Arlington show that, tho the difference between the strength of signals by night and by day is much less at long wave lengths than at short, still there is no approach to actual equality in strength of day and night signals even for very long waves. Thus, with Clifden sending at 7,000 meters, at Brant Rock the received current thru 25 ohms resistance was from 35 to 55 micro-amperes by day, rising to 100 micro-amperes by night (for autumn and winter). In summer, the day signals were generally inaudible, varying between 7 and 12 micro-amperes. The night signals were much louder in this case also.

ROBERT H. MARRIOTT: The Standardisation Committee of the INSTITUTE will consider the shunted-telephone method of recording the strength of signals, as well as other methods intended for the same purpose, in order that Professor Kennelly's suggestion of the coöperation of amateur and commercial stations in scientific investigation of transmission may be put into practise shortly.

ROY A. WEAGANT: It is quite certain that much of the value of data obtained by amateurs on the strength of signals of certain commercial stations will be lost unless the commercial stations can be induced to keep a definite record of their radiation at various times. The current value in the antenna, the quality of the note, and the wave length are necessary for such a record. This is not usually done.

GUY HILL: According to your theory of reflection from conducting upper layers in the atmosphere, might not continuous ("undamped") waves be reflected more perfectly than damped wave trains? This question has a bearing on an effect we wish to explain, namely the apparent greater range achieved by given amounts of energy when in the form of continuous radiation. More observations on this point are needed.

A. E. KENNELLY: I think that if a steady stream of waves were emitted, they might show these reflections more markedly; and possibly greater ranges might also be attained by

their use for a stated amount of energy. But it is as yet an obscure point.

JOHN L. HOGAN, JR.: The point that Mr. Hill suggests regarding the prominence of reflection (and interference) effects with sustained waves is well substantiated by some observations presented by Dr. de Forest before this INSTITUTE. (Proceeding of the Institute of Radio Engineers, Vol. 1, Number 1, page 37.) He shows that if continuous waves pass from a transmitting station to a receiving station by two different routes, one of which is direct and the other of which is caused by reflection of waves which strike elevated cloud layers, very marked interference effects will be produced at certain frequencies. That is, at definite wave lengths the signals will be either markedly weakened or strengthened. Change of wave length may bring the signals to normal strength.

It is possible that these selective absorption effects are phenomena based on slow resonance, and that therefore they should be more marked with sustained than with damped waves. Instances of marked reflective amplification may be responsible for the transmission of long-distance signals which have brought forward the contention that the range to be attained by the use of sustained waves is greater for equal output than with damped waves. I have discussed this claim with Dr. Austin while in Washington, and he appeared very sceptical concerning it. We felt that we had not enough data to warrant acceptance of it and that there should be no great difference in the transmission of sustained waves as compared with those of low decrement.

It seems to be a wonderful confirmation of Professor Kennelly's hypothesis that even such observations as those taken between Clifden and Glace Bay (where signals were graded in strength by simple aural classification as "very strong," "strong," "moderate," "weak," and "very weak"), are in such good accord with the theoretical conclusions.

In connection with abnormal daylight absorption treated by Dr. Kennelly, it is interesting to note that the value and relation for normal daylight absorption have been partially confirmed.

In 1911, Drs. Austin and Cohen, on the basis of experimental work performed from Brant Rock, gave the following law for the received antenna current I_2 in terms of I_1, the transmitting antenna current, h_1 and h_2, the heights of transmitting and receiving

antennae, λ the wave length, and s, the distance between the stations.

$$I_2 = \frac{4.25\, I_1\, h_1\, h_2}{s}\, \varepsilon^{-\frac{\alpha s}{\sqrt{\lambda}}}$$

where α is a constant, equal approximately to 0.0015.

These experiments covered several types of antennae, and distances up to 1,000 miles (1,600 km.) with various antenna currents. The current for audibility (thru an equivalent resistance of 25 ohms) was taken as 10 microamperes. It appears that we need only 5 microamperes, or with the heterodyne receiver less than 2.5 microamperes. Making this change in the equation above, the results had in the recent Arlington-Salem tests offer good substantiation of the relation. With a sending antenna effectively 450 feet (138 meters) high, and a receiving antenna of 130 feet (40 meters), groups of thirty-word messages have been consistently received by daylight up to a distance of 2,383 miles (3,830 km.). From this it can be shown by a graphical solution of Austin-Cohen equation that the daylight range of an Arlington-type station to a similar station is 2,920 miles (4,700 km.) at a wave length of 4,000 meters; and rises to 3,400 miles (5,500 km.) at a wave length of 10,000 meters. (Further details of these heterodyne experiments, and the Arlington-Salem tests are given in the latter portion of the next paper in this issue of the Proceedings. Editor.)

I wish to endorse Professor Kennelly's suggestions. I trust that the observations will cover all parts of the twenty-four hour day, and that transmitting station records, as recommended by Mr. Weagant, may be secured.

LLOYD ESPENSCHIED: Such experiments as just proposed can be best carried on by the Navy. They would materially add to the efficiency of the Weather Bureau's work, if properly planned.

CAPT. F. J. BEHR (Coast Artillery Corps, U. S. A.): This subject is one of great interest to us; particularly the relative advantages of "damped" and "undamped" waves. These meetings of THE INSTITUTE OF RADIO ENGINEERS are doing yeoman service in calling attention to these points and the proper method of investigating them.

H. E. HALLBORG: We should try more transmission experiments between stations lying north and south, so as to be able to compare ranges with those lying east and west. It has already been noted by ship stations that the transmission of signals in a north and south line is superior to that in an east and west line.

GUY HILL: Referring to the surface waves, Marconi has used wires on the ground for long distance reception, and some time ago Fessenden received messages over 600 miles on ground antennae.

A. E. KENNELLY: We may assume, in the present state of the theory of radio-telegraphic received signals, that the voltage of a signal received from a given steady wave-train is directly proportional to the maximum height of the receiving antenna above the plane of the equivalent perfect ground surface. The electric energy of the signal, however, is of course proportional to the received voltage and the received quantity. The quantity probably depends on the extent of wave surface area on the wave-front intercepted by the antenna. If this way of considering the matter is correct, a very low antenna of great length might give as strong a receiving signal as a high antenna of small width or surface area.

ALFRED N. GOLDSMITH: There seems to be a non-reciprocity of sending and receiving properties, on which Lord Rayleigh has already commented. A high antenna is necessary for transmission, but since reception of messages is largely accomplished on surface waves (at least for long distances) a low receiving antenna suffices.

CHARLES A. LE QUESNE, JR.: In a recent number of the Telephone and Telegraph Age I find a reference to some experiments by Austin Curtis on an effect of moonlight on reception of signals. The effects presented were similar to those for sunlight.

ALFRED N. GOLDSMITH: These experiments were originally disclosed in The London Electrician for March 21, 1913, (page 1104) and May 2, 1913, (page 143), and they have been considered by Dr. Eccles in the same periodical for March 28, 1913, (page 1144).

AUSTEN CURTIS (by letter): In connection with the erection of a station in Boa Vista, Amazonas, Brazil, for the Brazilian Department of Agriculture (Commissao da Defeza da Barracha), I had the opportunity of making some highly interesting observations on atmospheric influences on radio signals. I am indebted for the opportunity to Dr. Roderick Crandall, Chief Engineer of the Commission for this section. Boa Vista is in the extreme northern part of Brazil, latitude 2° 52′ N., longitude 60° 40′ W., in open prairie country, at a low elevation.

The observations covered the period between November, 1912, and May, 1913. During this time practically no rain fell, dew being absolutely unknown. The humidity was from 50 to 65 degrees, and it was possible to see thru the very clear air 50 to 100 miles.

The effect of moon rise on the strength of radio signals will first be considered. It has been observed with the following stations: NPG (Trinidad), 600 miles north, 600 meter wave; DQC (unknown ship), 600 meter wave; Y (Yquitos), 870 miles west, 1,800 meter wave; Z (Lima), 1,250 miles southwest, 1,600 meter wave; MA (Manaos), 390 miles south, 1,350 meter wave. All but the first two of these (on which observations were taken only once) are Telefunken stations, 500 cycle, and low damping.

In the tropics, full moon rise is at about 6 P. M., and falls about 50 minutes later each successive night. Since no stations within range began sending before 7 P. M., no observations were possible on the night of full moon or the night thereafter; this restricted the range of measurements to the third, fourth, and fifth nights after full moon. After this, the moon light is much reduced, and the effect disappears.

The curves given in Figures 10 and 11 are typical of the complete cycle of changes. This cycle consisted in general of a rise in signal strength, a drop, a second rise, a second drop, and a final rise to a constant strength which was maintained the remainder of the night. The time after moon rise at which this effect occurred varied considerably, being sometimes as much as 20 minutes later. In one case (Yquitos sending), it was noted that after moon rise at Yquitos, the signals received at Boa Vista (in full moonlight) increased suddenly and remained thereafter at the higher value.

Particularly worthy of notice is the following peculiarity: in all cases where the distant station continued to send for a sufficient

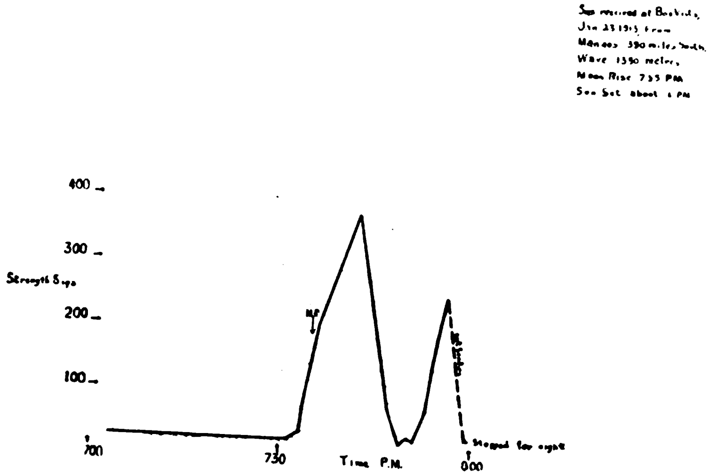

Figure 10

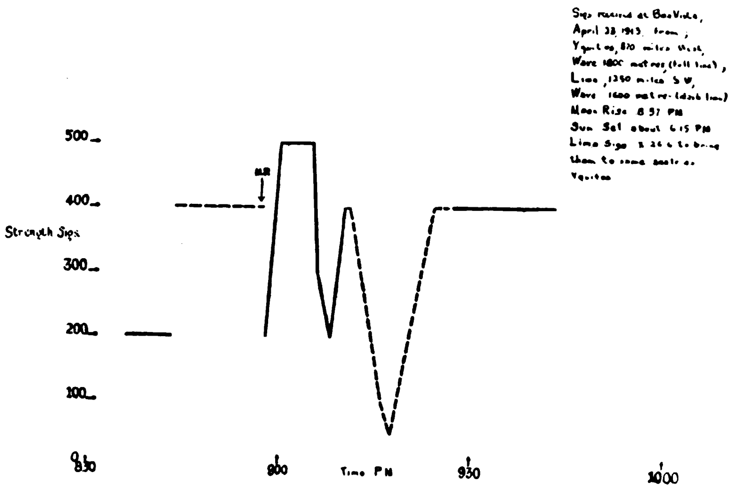

Figure 11

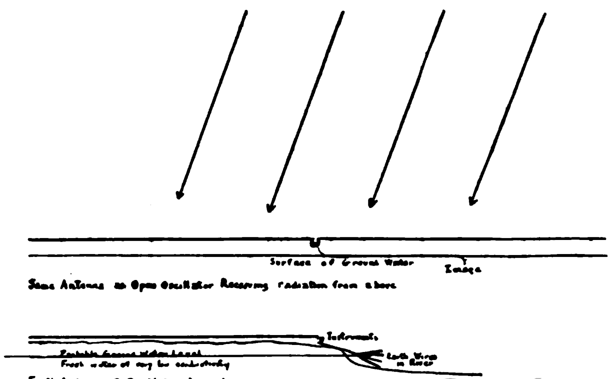

Figure 12

length of time, there were *two minima* in the strength of signals with *9 to 10 minutes* between them.

The fact that the time at which the effect occurred was independent of the distance and bearing of the sending station, and that in two cases two different stations followed the same cycle of signal variation, is conclusive evidence that the effect is either at the receiving station, or in the atmosphere directly above or almost directly above the receiving station. This reasoning leads me to the belief that the waves received (on the particular ground antenna used) were free space waves, coming from a height great enough to make the angle of incidence with the earth and the ground antenna used not very far from 90°.

Dr. Eccles has attempted to explain the moon rise effect by considering it as a continuation or complication of the sunset effect. A little consideration of tropical conditions will show this to be very improbable. The sun sets in the tropics at about 6 P. M., and it is dark in fifteen minutes. Yet I have observed the moon rise effect as late as 10.30 P. M. and nearly twenty times.

Considerable difficulty is experienced is obtaining a complete curve of the cycle of signal intensity changes because of the irregular times of transmission of the stations. So far as the magnitude of the drop was concerned, it varied enormously; all the way from 2 to 1 up to 10 to 1. When static from a distant source was heard, its intensity change always followed that of the signals received, keeping the same relative strength. The method of deciding the distance at which the static originated was rough but fairly reliable. Remembering that it was possible to see nearly 100 miles from the station, on evenings when distant lightning could be seen, and the static was sharp and snappy in character, the static was termed local atmospherics. When the night was perfectly clear, no traces of lightning could be seen, and yet there was a continuous muffled roar of static of about 500 times audibility in the telephones, the static was assigned to distant sources.

Two aerials were employed in the experiments, and these will be described in detail. The ground antenna was 450 meters long to the instruments, 5 to 6 meters high, made of 2 No. 12 copper wires. The ground consisted of a fan of 10 wires 50 meters long in the river bed. The natural period was 3,000 meters. (During the first month, long leads to the instruments brought the natural period up to 4,000 meters.) The bearing of

the antenna was N. and S., the instruments were at the S. end, and the free end of the aerial was open. The ground underneath was absolutely dry and sandy, and there was no rain or dew. The underlying strata consisted of an "ironstone" conglomerate, about 10 meters deep and 10 meters thick; under this a layer of clay, with ground water at the junction of the clay and the conglomerate. The second aerial was a T antenna, on the bank of the river, bearing N. E. and S. W., 40 meters above water level, 200 meters long, 2 wires, and of natural wave length of 1,200 meters. A list of stations heard is given at the end of this note.

The ratio of the strengths of the signals received on the two antenna was fairly constant for a given station provided that the signals showed no tendency to "swing," that is, vary suddenly; but when the signals did swing, they swung *independently* on the two antennae. This leads to the belief that, at night at least, the types of wave received on the two aerials were different. It may be mentioned that the two aerials were far apart, and that one was always ungrounded while measurements were being made on the other.

The following experiment was then tried as a further comparison between the two antennae. Half of the long antenna was lowered to the ground, the T antenna remaining undisturbed. This change reduced the signals received at night by about 33 per cent, while it reduced day signals by 87 per cent. That is to say, the influence of the height of the long antenna on its capacity for reception was 2.6 times as important during the day as at night. This is evidence that the radiation received in the daytime is principally in the form of surface waves, and that at night the energy is in the form of free space waves reflected or refracted from the upper layers of the atmosphere.

The signals received from Manaos and Santarem at night from the middle of February to the middle of April showed very extraordinary and sudden fluctuations. The audibility factor would suddenly change from 25 to as much as 1,000, in a period of five minutes. This effect, which had no connection with the moon rise, disappeared about the middle of April. Yet during the same period the signals received by day from Manaos were perfectly steady.

A study of the weather during this period at different points on the Rio Branco showed that the northern edge of the rain belt was just midway between Manaos and Boa Vista. A

brief consideration of the meteorology of the tropics will make this clearer. The rotation of the earth and the higher temperature of the equatorial regions combine to produce the N. E. and S. E. trade winds, which, meeting somewhere near the equator, cause a rising sheet of heated air, which carries with it rain clouds, and thunderstorms. This belt is several hundred miles wide, but its height is problematical. At sea, this region between the trade winds is known as the equatorial calm belt; on land it gives rise to the rainy season. It moves north and south with the sun, being farthest north in July or August.

As practically all the tropical thunderstorms are concentrated in this region, its position determines the intensity of static for the tropical regions. It seems probable that the swirls and air currents which exist at the contact edge between the N. E. trade winds and the rising air currents of the calm belt disturb the electrically stratified structure of the air in that region. This would cause the violent fluctuation of signal strength noted when the edge of the calm belt lay midway between Manaos and Boa Vista. The fact that the strength of signals returned to normal as soon as the northern edge of the calm belt came within 100 miles of Boa Vista shows that the presence of heavy clouds was not the cause of the fluctuations in strength. The occurrence of this swinging at night only, and at times when the point of reflection or refraction of the waves was in a region of disturbance, is further evidence that the waves received at night came thru the upper atmosphere and are refracted or reflected at a point midway between the two stations. They are therefore space waves; while the waves received by day are surface waves.

The co-ordination of all these results leads to the following conclusions:

I. That at night the ground antenna acts as if it were an ordinary Hertzian oscillator laid on the ground, the wire forming one-half and the ground giving rise to the "image." (See Figure 3.) Considered from this point of view, it will receive energy from or near the zenith most readily. (It is to be noted that the river formed the nearest conducting body to Mr. Curtis' ground antenna. Editor.) Further, any change in the height of the reflecting or refracting layer will affect the angle of incidence of the received waves, and consequently their strength. On this assumption, the moon rise effect would be caused by ultra violet light

disturbing the definiteness of the reflecting or refracting layer of the atmosphere.

II. The ground antenna acts in the daytime as if it were receiving surface waves only, for its efficiency is markedly dependent on its height above the earth.

III. Either surface or space waves may be received by night. as evidenced by the fact that variations in the strength of the received signals at the same time and from the same station on the two antenna are not proportionate. Probably the T antenna receives the surface waves by night mainly, and the horizontal antenna the space waves. Abnormal atmospheric conditions affect the two types of waves to different extents. This makes it possible that a proper combination of a horizontal with a vertical antenna for receiving would minimize the variations in the strength of received long distance signals.

Finally, it was noted that after a heavy rain, when the ground absorption was changed, daylight signals became weaker. The stations heard at Boa Vista were as follows: Using the horizontal antenna, regularly by day, Porto Velho, 700 miles S., 45 K.W. Marconi set, 3,500 meters, 4 to 10 times audibility; Manaos, 390 miles S.E., 45 K.W. Marconi set, 3,500 meters, 10 to 30 times audibility; Manaos, 390 miles S.E., 5-10 K.W. Telefunken set, 3,500 meters, 2 times audibility; Santarem, 500 miles S.E. over a high mountain range, 5-10 K.W. Telefunken set, 3,500 meters, 2 times audibility. In the night time: Manaos, Marconi, 300 times audibility; Porto Velho, Marconi, 200 to 300 times audibility; Manaos, Telefunken, up to 1,000 times audibility; Santarem, Telefunken, up to 300 times audibility; Cape Cod, Mass., 2500 miles N., 1,900 meters, 5 to 15 times audibility; Sayville, L. I., 2,500 miles N., at 1,800 meters, up to 50 times audibility, at 2,800 meters, up to 20 times audibility; Lima, 1,250 miles S.W., 1,600 meters, up to 30 times audibility; Yquitos, 870 miles W., 1,800 meters, up to 500 times audibility.

A. E. KENNELLY (by letter): Mr. Curtis' observations are important as to a direct effect of moonrise, upon received signals, at times other than full moon. As Dr. Eccles has pointed out, a full-moon moonrise effect is not distinguishable from a sunset effect. If, however, Mr. Curtis' observations can be confirmed by other experimenters, to the effect that moonlight influences are distinctly observable long after sunset, the phenomenon has great importance. Since moonlight is accepted as

nothing but sunlight reflected to us from the moon, it is reasonable to suppose that the effect of moonlight on received signals must be of essentially the same nature as that of sunlight, but very much weaker in intensity. It would be possible, however, for a moonrise action on signals to be much stronger than would be inferred from a consideration of the relative intensities of moonshine and sunshine, if the surface of discontinuity between ionised and un-ionised air were sharper, or more markedly defined, than in the case of sunlight. In other words, a shadow-wall of feeble moonlight might partly compensate in its sharpness for its lack of differentiation between light and shadow, and so produce reflective disturbances on signals out of proportion to the intensity of the light. The effects described by Mr. Curtis might possibly be explained on such a postulate; but it is not easy to see why the moon's shadow-wall should be relatively sharper than the sun's shadow-wall.

The valuable information contributed by Mr. Austen Curtis, as obtained at a single station, indicates how much knowledge could be secured by co-operative voluntary systematic observation, continued for years, among a number of observers, at many different stations.

It seems difficult to understand why two receiving antennae, such as Mr. Curtis clearly describes, should be responsive selectively to two very different types of wave transmission, such as he suggests. In horizontal extent, the two differ only as 450 meters against 200 meters, and in height above ground water, as 60 meters against 25 meters. Is it not worth exhausting every effort to explain the action of these two antannae, considering the independent swinging, on the basis of their difference of natural wave length (1,200 meters as against 3,000 or 4,000 meters) loaded to syntony, before accepting a theory of two different types of waves acting selectively? The conditions described are certainly unusual, and the phenomena reported are most interesting.

PROFESSOR GEORGE B. PEGRAM, of the Department of Physics, Columbia University (at which the INSTITUTE meetings are held), expressed the hope that, in view of the useful scientific and technical work done by the INSTITUTE OF RADIO ENGINEERS, the cordial relations between that body and Columbia University might continue to exist.

(The Editor, on behalf of the INSTITUTE, heartily shares this desire.)

THE HETERODYNE RECEIVING SYSTEM, AND NOTES ON THE RECENT ARLINGTON-SALEM TESTS.

By JOHN L. HOGAN, JR.

(Chief of Operating and Erection Department, and Research Engineer, National Electric Signaling Company.)

Much interest has been shown in the heterodyne receiver since its use in the recent test between the Fessenden stations of the U. S. Navy at Arlington, Virginia, and aboard the cruiser, Salem. These trials mark the first public use of the heterodyne system, which has often been called the greatest of Professor Fessenden's inventions; but, as a matter of fact, the method has been utilized in the National Electric Signaling Company's plants for a number of years.

It is the purpose of the present paper to explain the heterodyne principle, and to describe the apparatus by means of which it is put into practice. Since the invention involves a number of points which are quite outside the range of observation of the average worker in radio signaling, an introductory consideration of the fundamentals of receiving instruments in general is desirable.

Every radio receiver is composed of two main parts; an energy absorber and an indicator. In some special forms of apparatus these two elements may be physically combined, but functionally they remain as distinct as before. The relation between the energy received and the response of the indicator, together with the process whereby the receipt of that energy effects the indication, probably serves as the best basis for classifying receivers in radio signaling.

In the receiving instruments originally used (which were mainly various arrangements of coherers with auxiliary apparatus), there was provided a local source of potential energy which was capable of operating the indicating mechanism, but was not allowed to do so because of the presence of some obstruction. In general, the energy of the received waves overcame this obstruction and allowed the stored local energy to give a signal upon a sounder, a buzzer, a bell, or some other indicator.

After each action of the indicator the obstruction was automatically set up once more so that the cycle of operations described might recur. This method of reception is typical of the so-called relay-operating receivers, in which the received energy serves only to release energy from a local source, and in which the final indication is not proportional to the received signal intensity. It is true that some forms of "local energy" or indirectly acting devices, such as microphones, restore themselves very quickly, and may give roughly proportional responses; but in all receivers of the relay type a group of received waves operates to change local conditions at the receiver so that energy from a local source may operate the indicator.

The relay class of receivers has been practically abandoned and almost all modern equipments have instruments in which the indication is made by the energy of the received wave itself. This statement may seem somewhat startling to some, for there still persists the old conception that the power received at radio stations is infinitesimal, and can be discovered only by the use of a "very sensitive" apparatus called a detector. Of course, the fact is that the power of the received radio signals is often of the order of magnitude of the largest rates of energy delivery occurring in line telephony, and that the detector of a radio receiving system is ordinarily a much less efficient device than the magnetic telephone used in connection with it.

Almost all receivers used in modern radio stations have as their basis of operation some instrument which rectifies electrical currents. The rectifier may be of the gaseous, liquid or solid type, but in any event it acts solely as an energy transformer linking together the wave absorbing system (the antenna) and the indicating mechanism (which is usually a telephone). In these arrangements the energy which moves the telephone diaphragm is actually received from the transmitting station by radio, and local sources of energy are not relied on to operate the indicator. The result of this type of action is a response very different from that of the relay receivers, for now the signals are proportional to the received power, and are therefore characteristic of the stations sending.

Practically all arrangements proposed or used for the reception of radio signals may be classified as either relay or transformer devices, in acordance with the above outline. The filings coherer with its battery and relay is typical of the first division;

the "crystal" rectifier operating without battery is obviously representative of the second type. It has been experimentally demonstrated that the liquid "barreter" (electrolytic detector) and solid rectifying detectors are of the direct energy-transforming type, the only effect of a local battery on their operation being a change of sensitiveness, but no alteration in the principle of operation.

It is evident that if we could secure a better relay detector than the coherer it would be possible to use radio communication in many ways not now practicable. Unfortunately all detectors of this class seem to become very delicate so soon as their sensitiveness to incoming signal is made great. This delicacy results in false operation by static; and, together with a general instability in the instruments, makes them far inferior to the transformer type detectors. This is true in spite of the fact that all instruments of the second class are limited in their response by the amount of energy actually received from the given transmitting station. The ability to give responses proportional to, and characteristic of, the transmitting station seems to be the feature which has given the transformer or convertor detectors their tremendous superiority. And radiotelephony is strictly dependent on such detectors.

It has been attempted to overcome the energy limitation of the transformer receivers by arranging them to control a microphonic relay which would modulate the current from a battery at the receiving station in accordance with the received signals. All instruments of this sort have increased the delicacy of adjustment at the receiving station and have made operation difficult on account of their large amplification of atmospheric and other false signals. It is apparent that what is needed is a quantitative receiver which permits the use of local energy to assist in giving the indication, but which will operate only upon persistent received waves; that is to say, a *selective* amplifier is needed in order to increase the effectiveness of radio receiving stations.

The only receiver of this selective type is the heterodyne, the name of which (from the Greek words *HETEROS* and *DYNAMIS,* meaning "other" and "force") describes its method of action; viz., to give an indication by using energy both from the received wave and from a local source. The telephonic relay amplifiers which have so far been proposed, act like valves

turning on and off a direct current in amounts approximately proportional to any received impulse. The heterodyne acts by the conjoint operation of two alternating currents which mutually add and subtract according to the physical laws governing the interaction of wave motions. These interactions will be next considered.

It is an interesting fact that the same laws of interference or wave addition hold whether one considers periodic displacements in water, air, "ether," or any other medium. If two wave motions occur in the same medium at the same time, the resulting action may be determined graphically by adding the ordinates of curves representing each of the separate waves. These curves are usually drawn to show displacement at a given point as time goes on, or else to show the wave form in a certain region of space at some assumed and definite instant of time. It is unnecessary actually to draw the curves, since the algebraic addition of expressions which give the displacements due to each of the component wave motions as functions of time or space will result in an equation expressing the resultant displacement.

The clearest conception of interacting wave motions may be gained from graphical considerations. Figure 1 represents two sine waves, A and B, progressing thru the same medium, and combining to give a resultant larger wave C. From the curves it is seen that frequencies of the fundamental waves are the same, and that the amplitudes are the same. Since both start at the same instant, they always remain in phase, and their effects are mutually additive, so that the resultant wave has an amplitude twice as great as either of the component waves.

Using the following notations, we can easily express the mathematical relations for the addition of the waves shown in Figure 1: t = time, n_1 = frequency of the wave shown on axis A, i_1 = instantaneous amplitude on curve A, I_1 = maximum amplitude on curve A. The same letters, but with subscript 2 refer to corresponding quantities of the wave plotted along the B axis. The curve A is represented by

$$i_1 = I_1 \sin \omega_1 t \tag{1}$$

and that of B is given by

$$i_2 = I_2 \sin \omega_2 t \tag{2}$$

where ω_1 and ω_2 are equal respectively to $2\pi n_1$ and $2\pi n_2$.

The sum of these two expressions will result in an equation of which the curve C is the locus, namely:

$$i = i_1 + i_2 = 2 I_1 \sin \omega_1 t \tag{3}$$

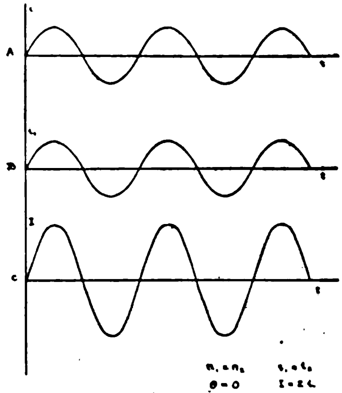

Fig 1

Figure 1

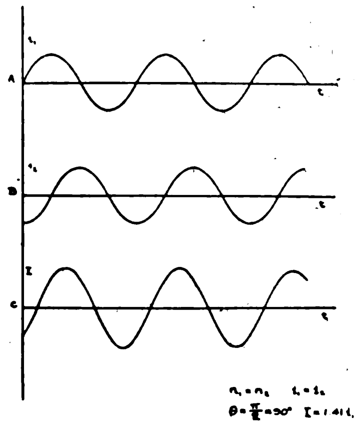

Fig 2

Figure 2

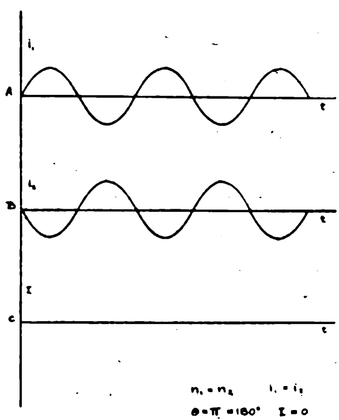

Fig 3

Figure 3

In the case shown in Figure 1, the waves travel, so to speak, hand in hand, and therefore always assist each other. If the wave B had started slightly later than A, for certain portions of time they would be opposing each other. A case of this sort is shown in Figure 2, in which the wave B starts 90° (or $\frac{\pi}{2}$ radians) later than wave A. This angular difference of starting is called the phase displacement of the second wave, and is represented by the letter θ.

By graphically adding the curves A and B, that of C is arrived at, and it is seen that in this case the maximum amplitude instead of being twice as great as that of the component waves is only 1.41 ($=\sqrt{2}$) times as large. The frequencies and original amplitudes have remained as in Figure 1. The reason for the change of the amplitude of the resultant wave is, of course, that for Figure 1 the maxima of the resultant waves occurred at the same time, whereas in this case they do not. The graphical result may be confirmed mathematically by a process similar to that for Figure 1. The following expression:

$$i=I_1 \sin \omega_1 t+I_1 \sin (\omega_1 t-\theta) \qquad (4)$$

shows the addition of two terms, the first representing curve A, and the second, curve B. By a simple trigonometric and algebraic transformation, equation (4) becomes

$$i=I_1 [\sin \omega_1 t \, (1+\cos \theta)-\cos \omega_1 t \sin \theta] \qquad (5)$$

For the case of Figure 2 we have assumed the phase displacement 90°, therefore $\sin \theta = 1$ and $\cos \theta = 0$. So that equation (5) becomes

$$i=I_1 (\sin \omega_1 t-\cos \omega_1 t) \qquad (6)$$

$$=I_1 [2 \cos 45° \sin (\omega_1 t-45°)] \qquad (7)$$

$$=1.41 \, I_1 \sin (\omega_1 t-45°) \qquad (8)$$

Expression (8) exactly agrees with the graphical results of Figure 2.

It is seen that as the phase displacement is increased, the two component waves oppose each other for larger portions of the total time. From this it would be expected that for some value of θ the two waves might completely neutralise, and there would be no resultant action. That this may occur is shown in Figure 3, where two waves of the same frequency and amplitude as in Figures 1 and 2, but having a phase difference of π radians or 180° are shown. The sum of these two waves is zero at all points. Indeed, if we substitute for θ in equation

(5), the value 180°, we obtain immediately for the resultant:

$$i = 0.$$

Evidently the addition of two sine waves of the same frequency, but of different phases, will produce a new sine wave having an amplitude lying between the difference and the sum of the component amplitudes as the phase difference varies from 180° to 0°.

However, if the frequencies of the A and B waves are not equal, the amplitude of the resultant wave will not be constant, but will be affected by the constantly varying difference of phase of the component waves. The complete mathematical solution of this case is somewhat complicated, but a clear idea of the phenomena involved can be obtained by the graphical method. It will be found that in general, the result of the addition (which includes subtraction or negative addition) of two waves of different frequencies is to produce a third wave having a fundamental frequency of the same order, but varying in amplitude from the difference of the component amplitudes to their sum. This variation in the size of the resultant wave is periodic, and occurs at a frequency equal to the difference of the frequencies of the component waves.

This regular, periodic variation of amplitude forms the basis of the entire science of harmony in music. The waxing and waning of a wave resulting from the addition of two notes of slightly different pitches form what are called "beats." Figure 4 represents two waves of different frequencies, together with the resultant wave found by adding them point by point. The A wave, shown on the top axis, is taken to have a frequency of 250 per second, while the B wave is of frequency 200. The amplitudes are seen to be the same, say 10; and the difference in frequencies is 50 per second. On the three diagrams, the axes extend for a distance representing one-tenth of a second, so that 25 of the higher frequency and 20 of the lower frequency waves are shown. Examination of the C axis shows that, as was to be expected, there are 5 complete beats or periodic variations, which correspond to a beat frequency of 50 in one second.

In every case so far considered, the component waves have had the same amplitude. Figure 5 shows the addition of two waves having the same frequencies, as in Figure 4, but with amplitudes of 10 and 2 respectively. It should be noted that the variation of amplitude is from $I_1 - I_2 = 8$ to $I_1 + I_2 = 12$, and that

the beat frequency is the same as in Figure 4. It should also be noted that whereas the smaller component wave B has an effective amplitude of only 2, the variation in the resultant wave is twice that. These theoretical considerations of the addition of wave motions may be verified experimentally.

We may take two organ pipes and connect them to a tank of compressed air thru separate valves, so that they may be blown individually or together. One of the pipes is of variable pitch, its frequency being alterable thru a considerable range. If both pipes adjusted to equality of pitch are blown simultaneously, a note of this pitch and of a volume twice as great is secured. If it were possible to blow both pipes so that they vibrated in opposite phase, it would be possible to secure complete neutralization of sound, that is, silence. This cannot be done experimentally with organ pipes. However, a somewhat similar effect may be secured by moving one of the pipes back and forth, and so changing the loudness of the resultant sound (due to direct transmission and indirect reflection from the wall) in some parts of the room. This indicates a change in the degree of addition or neutralization due to a variation in phase difference. These beats are also shown even more perfectly by the use of the clear tones produced by ordinary singing flames.*

If the two organ pipes have slightly different frequencies, the conditions of Figure 4 will hold. One pipe has been adjusted to 500 vibrations per second, corresponding roughly to the note C′ and to a wave length in air of 0.6 meter (2.2 feet). If the other has a slightly different pitch, when both are blown together, there will be produced a tone which shows a slow increase and diminution of volume, the number of beats per second being determined by the difference of the frequencies of the organ pipes. If the difference of pitch is slightly increased, the beats increase in frequency, and if the difference of frequency of the pipes is still further increased, the beat frequency increases till finally the fluctuations can no longer be heard. When both organ pipes produce sounds of the same intensity, the beats are very marked. But even when the tone from one pipe is made very weak by shutting off part of the air supply, the beats are still very distinct, as would be expected from inspection of Figure 5. As a rule, the beats are more prominent than the weaker of the two component

*(The experiments herein described were performed at the original presentation of this paper before the INSTITUTE. Editor.)

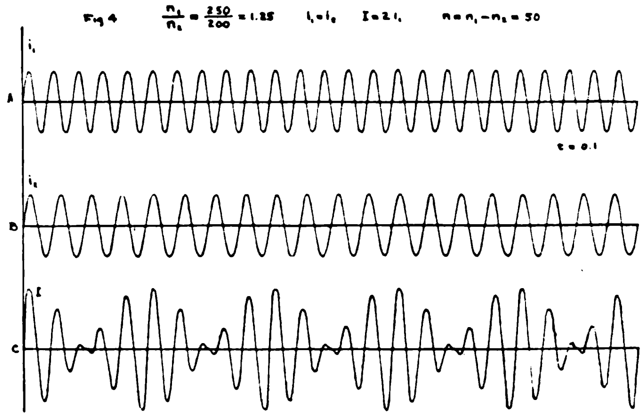

Figure 4

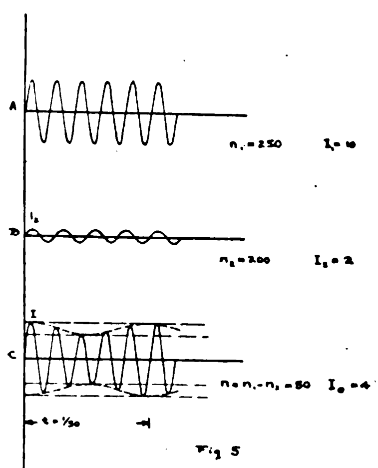

Figure 5

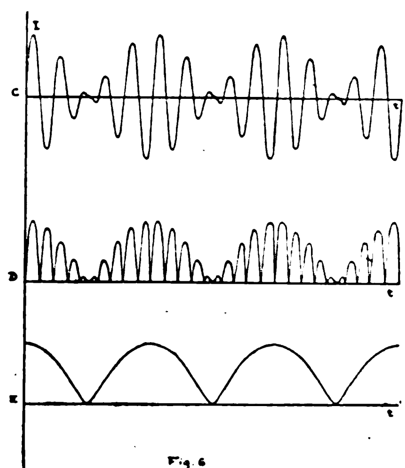

Figure 6

tones, and this fact is often made use of by engineers working in acoustic problems to determine the presence of a weak tone which cannot itself be heard because of other noises.

The acoustic effects described have their exact analogues in electricty. If we had two small alternators independently driven and with separate controlling resistances (so that their frequencies, phases, and amplitudes might be changed at will), it would be possible by varying the several resistances to secure all the effects shown in the preceding figures.

Changing the frequency of the interesting waves does not affect the production of beats so long as the difference between the frequencies is kept constant, except as the component or fundamental frequencies affect the responding mechanism. Responders or indicators are of two broad classes, polarized and non-polarized. A polarized indicator is one in which a displacement in one direction will produce a motion in a certain directon, and a dsplacement in the other direction will produce a motion in the opposite direction. Examples of this class are the ear and the ordinary magnetic telephone. In non-polarized indicators a motion is produced in a certain direction regardless of the polarity of excitation. That is to say, a positive displacement will produce the same motion as an equal negative displacement. Examples of this type of indicator are the static telephone and the magnetic telephone having no permanent magnet. Referring to Figure 4, and considering a wave motion in air represented by the C wave affecting a polarized indicator such as the ear, it is evident that the ear drum follows exactly the curve of excitation. It is also evident that as the frequency is increased indefinitely a point will be reached at which the ear drum cannot follow in its movements the rapid fundamental vibrations, tho it could move at a frequency corresponding to the beats. Air vibrations which approach and even pass this upper limit of audible vibration frequency may be produced by the use of a Galton whistle, and by moving this instrument back and forth in front of a reflector, beats in the high frequency note can be produced because of the interference between the direct and reflected waves. It is found that beats of sound can be heard up to the limit of audibility, but so soon as the whistle produces an air wave which cannot itself be heard, the beats become inaudible.

The reason for this can be seen from Figure 4 C. When the note frequency is so high that the inertia of the ear mechanism

prevents any response to individual half waves, the applied wave energy alternates so rapidly that its effects are alternately equal and opposite, and there is no tendency toward motion of the drum. When the fundamental wave itself produces no motion regardless of its intensity, it is quite evident that variations in this intensity will produce no effect, and therefore that beats are inaudible under these conditions. The beats really exist none the less, and this may be proved by noting that even tho they are inaudible to some persons, others whose ears have a higher limit of audibility can still hear the variations in amplitude of the fundamental whistling tone.

The conditions are completely changed, however, if, instead of a polarized device, there is used one which is non-polarized, or one in which there is given an effect proportional to the integrated applied energy, regardless of the polarity or direction of displacement. Figure 6 applies to an instance of the second sort. In this diagram, the curve along the C axis is exactly like that of Figure 4. If motion in the same direction is produced for either positive or negative displacements, such motion will be shown by the curve D of Figure 6, which is the curve C rectified. A little consideration will make it clear that in this case, as the frequency of the component tones is increased (provided their difference is kept the same), there will still be a motion corresponding to the frequency of the beats even tho the responding mechanism can no longer follow the indivdual waves. The motion which will result is shown along the E axis.

The possibility of building a radio receiver based on the beats principle should now be evident. If two radio frequency currents of slightly different periods are allowed to interact, there will be a periodic variation of amplitude of the resultant radio frequency current, and this variation or beat frequency will be equal to the difference of the two fundamental frequencies. As is well known, it is not possible to indicate the existence of a radio frequency current by means of a polarized indicator such as the magnetic telephone of the usual type, since the wave frequency is beyond the upper mechanical limit of response of such indicators. An air core telephone, or one without a permanent magnet, would give an indication when such currents passed thru it, since it belongs to the non-polarized class and operates in a manner analogous to that shown in curves D and E.

The development of the heterodyne receiver by Professor

Fessenden and the engineers of the National Electric Signaling Company may now be considered. Figure 7 shows the first device in which the heterodyne principle was employed. Here A and A′ are separate receiving antennae, B and B′ loading coils, and C and C′ additional coils so arranged that their resultant field will act upon the diaphragm D. If, at a transmitting station two sustained waves of slightly different frequencies are sent out, and at the receiving station one antenna is tuned to each, their conjoint action will result in a motion of the telephone diaphragm corresponding to the difference of their frequencies. Signaling may be effected by sending short or long groups of both waves simultaneously, or one wave may be generated continuously and the signals sent by starting and stopping the other one. It is evident that an economy may be brought about by transmitting only one wave, and generating the second frequency at the receiving station. Figure 8 shows the apparatus arranged for this method of operation, and in this sketch G represents a radio frequency generator, and F and H tuning inductance and condenser respectively. The local generator G is under the control of the receiving operator, and therefore the difference between its frequency and that of the waves received from the transmitting station may be varied so as to give vibrations of the diaphragm D corresponding to any musical note which the operator may prefer.

The form of telephone shown in Figures 7 and 8 was found not to be a very efficient receiver, so that the sensitiveness of the entire system was improved by the use of a thin insulating diaphragm carrying one coil, this being placed in the field of the second fixed coil C, Figure 9. With this arrangement the effect is the same as in Figure 8, except that the repulsion between the coils as well as attraction is used. A still further increase in sensitiveness was attained by substituting for the dynamometer type a delicate static telephone as shown in Figure 10. This arrangement, together with one equivalent to it (in which the static telephone was placed in a coupled circuit) has been used by the Company for some time, and is effective. The arrangement gives a sensitiveness equal to that of the usual detector for persistent waves, yet the selective power is much higher and the response to static far less. With the arrangement shown in Figure 10, I have personally received signals over distances of approximately 3,000 miles (4,800 km.), altho the static telephone

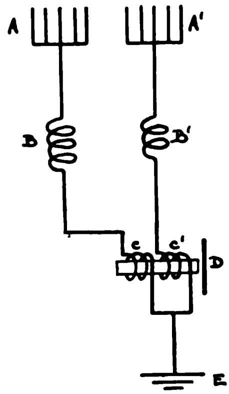

Fig. 7.

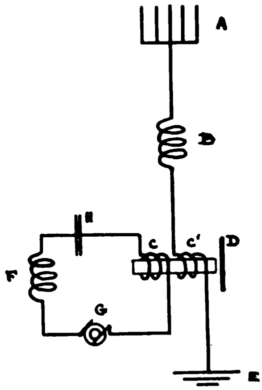

Fig. 8.

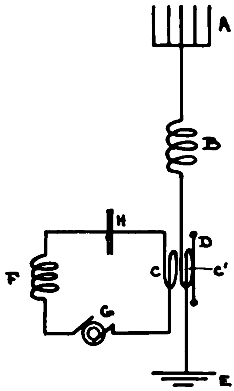

Fig. 9.

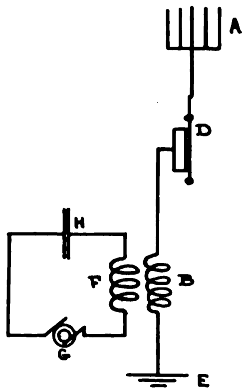

Fig. 10.

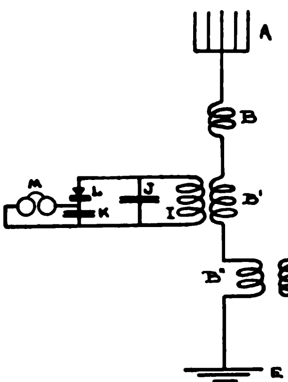

Fig. 11.

is notoriously insensitive, and such results might appear incredible.

A further reference to Figure 10 will serve to show how the effective receiving power of the static telephone is increased by the application of the heterodyne principle. From the sketch it is clear that any current flowing in the antenna by way of the static telephone D will cause a motion of the diaphragm. The sound energy produced by this action will be proportional to the electrical energy, that is, to the square of the antenna current. If we consider the received wave as setting up the antenna current, it is seen that if the former is of audible frequency and sufficiently powerful, the diaphragm will give an audible indication of frequency twice that of the received wave. If the frequency is increased beyond that to which the diaphragm can respond, motion will be produced only at the beginning and ending of the trains of waves, and during all the time radio frequency current is passing, the diaphragm will remain in a state of steady strain. If such radio frequency waves are received in groups, there will be a pull on the diaphragm for each group, and the group tone will be produced with a strength proportional to the square of the antenna current. If we assume that no waves are being received, but that the generator G is in operation, the effects produced will be the same as outlined above. So long as the generator produces a stream of sustained radio frequency current, the diaphragm will remain strained toward the fixed plate, and motion will be produced only when the generator current is altered in value. If a stream of waves is received by way of the antenna, and at the same time the local generator is operated to produce currents of a slightly different frequency, the effects in the antenna may be considered to be those shown in Figure 4, where A represents the locally generated current, and B shows that from the received wave. These two series of alternating impulses acting simultaneously on the static telephone produce effects corresponding to the rectified form shown in Figure 4 C. Since attraction of the telephone diaphragm results from any increase of the electromotive force, regardless of the polarity, the tendency toward movement is shown by Figure 6 D. Inasmuch as the inertia of the diaphragm prevents the indication of the individual waves, its actual motion is shown in Figure 6 E. If the incoming wave has a frequency of 100,000 cycles per second (corresponding to a wave length of 3,000 meters) and that

of the generator is 101,000, a musical beat tone of frequency 1,000 will be produced by the static telephone and the intensity of this sound will be *proportional to the square of the beat variation.*

What value this action has in increasing the strength of signals may be determined from a brief consideration of a mathematical explantion which has been proposed. Assuming a receiving current of i_1 milliamperes, it is clear that if the train be started and stopped by some form of interrupter the signal will be measured by $(i_1)^2$ audibility units since the response is proportional to the square of the antenna current. If, instead of interrupting the incoming wave, there is induced in the antenna a second locally generated radio frequency current of i_2 milliamperes, the resulting instantaneous valve will be

$$i = i_1 + i_2 \qquad (10)$$

The component of the antenna current measured by i_1 varies from zero to its full value as the signals are started and stopped, but the value of i_2, which is generated at the receiving station, remains constant. If the audible response were proportional to the current, there would be no increase in it due to adding i_2. But since this response is proportional to the energy, or current squared, it is proportional to

$$i^2 = (i_1)^2 + 2\, i_1\, i_2 + (i_2)^2 \qquad (11)$$

Considering now the various components of this antenna energy factor, the part represented by $(i_1)^2$ starts and stops with the signal dots and dashes, but is of inaudible frequency, and therefore does not add to the tone signal in the static telephone. The component $(i_2)^2$ is constant, and therefore forms no part of the signal. The remaining component, $2\, i_1\, i_2$ measures the signal, since it represents the beat itself. The response is proportional to the energy of the beat variation, that is, to

$$(i_1 + i_2)^2 - (i_1 - i_2)^2 = 4\, i_1\, i_2 \qquad (12)$$

The effective amplitude is one-half of this. It is therefore clear that with the heterodyne receiver it is possible to get a signal y times as loud as with the plain static telephone, where y is defined by

$$y = \frac{2\, i_1\, i_2}{(i_1)^2} = \frac{2\ i_2}{i_1} \qquad (13)$$

From (13) it is seen that if the current drawn from generator G, (Figure 10) is less than one-half that received, there will be no improvement in the signal, but as soon as more is taken

from the local circuit an increase in effective sensitiveness is had. Values of current for an actual case may be taken as $i_1=1$ milliampere and $i_2=100$ milliamperes, which gives a value of $y=200$. In other words, under these conditions the signals received by the heterodyne will be 200 times as loud as tho the plain static telephone were employed with no local excitation. Since such a ratio of i_2 to i_1 is not at all out of the ordinary, the increase of sensitiveness which makes possible reception over distances of 3,000 miles (4,800 km.) may easily be understood.

It should be noted that the theoretical amplification factor expressed by y in equation (13) holds only for the interaction of two sustained sine waves. If damped waves are used, the beats will still be generated, but they will become weaker as the decrement of the received wave is increased, since as the beats tend to build up, the decreasing amplitude of one of the component waves will tend to reduce them. With highly damped discharges such as those produced by atmospheric disturbances, only a portion of a beat is produced, and therefore the response to static is small. But with the waves of a well-adjusted spark station of the synchronous rotary or fixed quenching gap types the amplitude ratio may reach comparatively large values. This obviously provides a means for selecting persistent signals and eliminating undesired atmospheric disturbances.

The heterodyne receivers described above are limited in practise by the low sensitiveness of the indicator, but this handicap has been removed by the adoption of the type now in use. This last arrangement is shown in Figure 11, where A and E represent antenna and ground, and where B′ and B″ are coils forming the antenna-to-ground circuit. I is a secondary coil and J a tuning condenser, K and L are respectively rectifier and telephone condenser, and M represents a magnetic telephone of the usual type. F G H shows the ordinary local generating circuit, coupled to the antenna thru the coils B″ F. In this apparatus the action is exactly as described above, the rectifier-telephone combination taking the place of the other non-polarized receivers. Referring to Figure 6 the action may be explained by considering that the C curve represents the currents in the radio frequency circuits, while rectified currents pass thru the telephone windings and produce a motion of the diaphragm corresponding to E. It is clear that in this arrangement of apparatus the amplifying power of the heterodyne system may be combined with the

sensitiveness of the normal rectifier and telephone. The difficulty due to the delicacy of the usual detector has been overcome, and it is possible to get tremendous amplifications of sustained waves and very valuable increase of signal intensity even when receiving from spark transmitters.

NOTES ON THE RECENT ARLINGTON-SALEM TESTS

Heterodynes of the type last described were installed at Arlington and aboard the Salem for the recent tests between those stations, and were used as the extreme distances were approached. During these trials the greatest amplification factor measured was 12 times, and the average thruout the test was about 5. That is to say, spark signals from Arlington or from the Salem were received on the heterodyne an average of 5 times louder (as measured by the audibility factor) than upon the electrolytic detector operating alone. This increase in effective senstitiveness, together with auxiliary apparatus of especially efficient design, made possible the great communication distances attained, altho even without the heterodyne new records for consistent communication between ship and shore would have been established. In connection with reports of this test which have appeared in various newspapers and scientific periodicals, it should be noted that the spark transmitter and Fessenden receiver were used for all official communication trials, but that a number of other receivers, including a ticker, were placed aboard the Salem by the Navy Department for some special tests. In some of these experiments an arc transmitter which had been temporarily installed at Arlington was used. A statement has been made to the effect that signals from the arc were received further than those from the spark transmitter, and this in itself is true, altho it leads to an erroneous idea as to the reasons for the occurrence. The explanation is simply that the heterodyne was used for receiving all signals at long distances, whether from the arc or from the spark transmitter, the ticker receiver having been abandoned by the Navy engineers within the first few days of the cruise, since results from it were not to be compared with those obtained with the heterodyne.* The heterodyne amplifies sustained waves such

* Dr. Austin is of the opinion that the rotary ticker used on the "Salem" was probably in some way defective, as it did not appear more sensitive than the electrolytic even, altho ordinarily it shows a sensitiveness of from three to ten times greater.—Editor.

as those from the arc more than waves occurring in groups (such as produced by the spark transmitter) and it is this fact, rather than anything else, which explains the larger transmission distances quoted. In this connection it is also interesting that while "D's" were received from the arc transmitter further than from the spark apparatus, no daylight message test was made with the sustained waves, and hence no communication data such as that upon which the main test was based could be obtained for arc sending.

The heterodyne of Figure 11 is seen to consist of a standard receiving set associated with a local generating circuit by means of an inductive coupler. The generator G may be an alternator such as that shown in Figure 12, which is a 2 K.W. machine capable of generating frequencies up to 100,000 cycles per second, or it may be an arc or other form of oscillation producer. Figure 13 shows a unit containing variable inductance and capacity for all wave lengths from 600 to 11,000 meters, such as was used at Arlington and aboard the Salem. Figure 14 shows the sound-proof receiving room at Arlington with the apparatus used in the scout cruiser test, the heterodyne generator standing at the right hand and the usual receiving apparatus at the left side.

A further example of the amplifying power of the heterodyne receiver is found in a test between Boston and New York some time ago in which the antenna current of the spark transmitter at Boston was cut down, and the intensity of the signals received at Brooklyn measured by the shunted telephone method both on the regular receiver and on the heterodyne. The results are given in the following table:

BOSTON TO NEW YORK.

TRANSMITTING ANTENNA CURRENT	AUDIBILITY FACTOR		RATIO
	ELECTROLYTIC	HETERODYNE	
20 amp.	108	600	5.5
10	22	130	5.9
7	19	124	6.5
4	6	100	16.6
1	0	10	Infinite

From this it is seen that even with spark signals it is possible to read on the heterodyne messages which could not be heard at all on the regular receivers, and this of course greatly increases the distances over which radio communication is possible.

The quantitative results secured on the scout cruiser test permit an experimental verification of the Austin-Cohen transmission

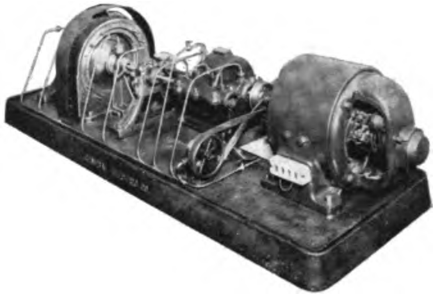

Figure 12
2 KW-20,000 RPM-110 Volt Generator
100,000 Cycles, Single-Phase, Gear-Connected to 2000 RPM-120 Volt Direct Current Motor.

Figure 13

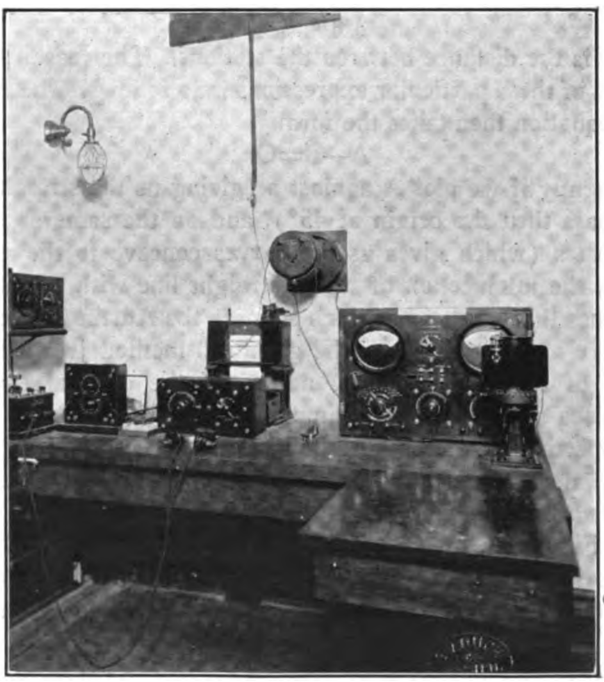

Figure 14

equation. In Figures 15, 16, 17, and 18, the curves give the values of the audibility factor calculated in terms of the distance between the stations. The crosses show the actual observations, and it will be seen that the agreement is quite satisfactory. Having determined the relations between the audibility factors, antenna currents, heights of antennae, wave lengths, and distance for ordinary receivers, and also for the heterodyne receiver, it is possible to compute the latter's communication ranges under any set of assumed conditions. Thus, by selecting constants which would apply to two stations of the Arlington type, it is possible to find suitable communication distances for various wave lengths and desired intensities of received signals, and so to arrive at feasible separations for a chain of similar plants. The results of such a series of calculations are shown in Figures 19, 20, and 21. These figures are the result of a graphical method of solving the Austin-Cohen equation. In them A_f represents the audibility factor, I_s the transmitter current, h_1 and h_2 the heights of the transmitting and receiving antennae respectively, and A and B are given the following expressions:

$$A = s$$

$$B = \frac{392\ I_s\ h_1\ h_2}{\lambda\ s\ \varepsilon^{\frac{0.0474\ s}{\sqrt{\lambda}}}}$$

where s is the distance between the stations. The reason for the adoption of these particular expressions is as follows. The Austin-Cohen equation then takes the form

$$A—B=O.$$

Consequently if we plot A against s (giving us the straight lines which pass thru the origin at 45°), and on the same sheet plot B against s (which gives us the curves concave to the axes as shown), the intersection of the A straight line with the B curve determines that value of s which satisfies the Austin-Cohen equation. We are forced to use the graphical method just described because of the transcendental nature of the original equation, which does not permit of a simple algebraic solution.

Inspection of the curves shows how markedly the signaling range of the stations increase as the required audibility factor is diminshed and as the wave length is increased.

In Figure 22, the full line gives the strength of signals from Arlington at night, as plotted from actual observation on the audibility factor at various distances. The dashed curve gives

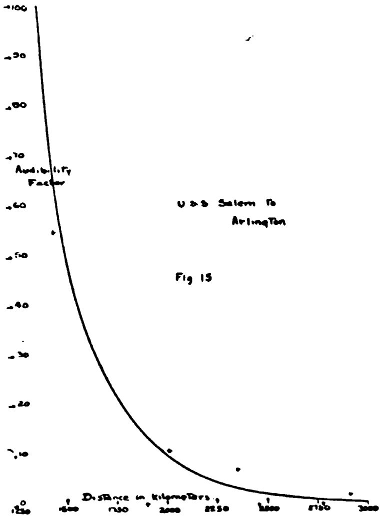

Figure 15

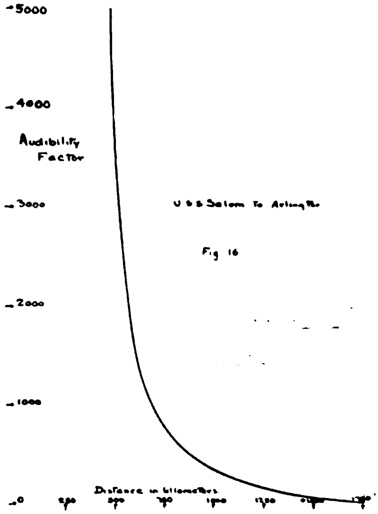

Figure 16

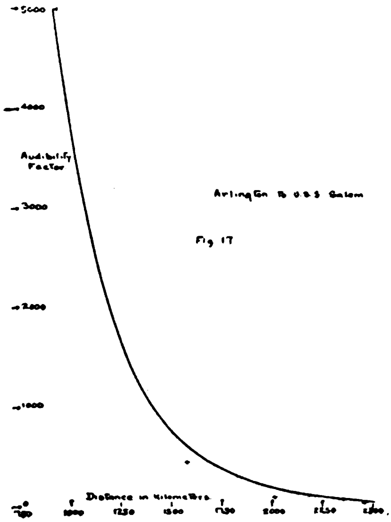

Figure 17

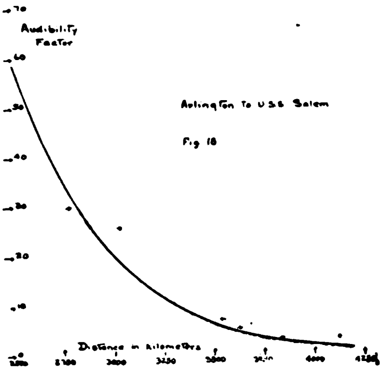

Figure 18

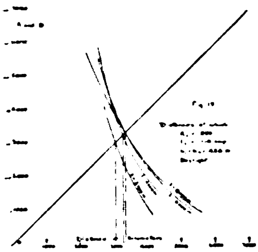

Figure 19

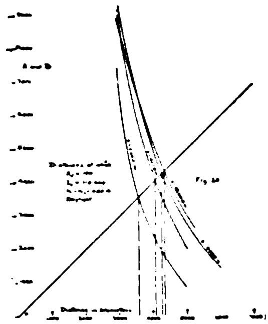

Figure 20

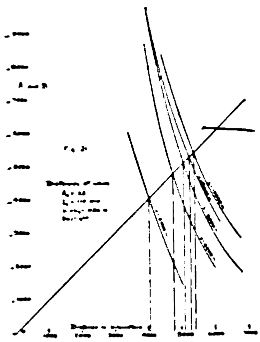

Figure 21

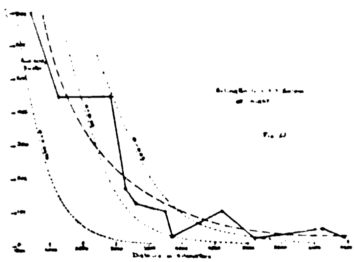

Figure 22

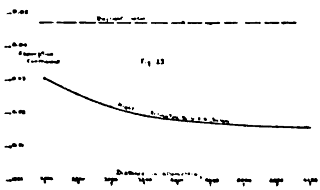

Figure 23

the smoothed average of these observations. The three dotted curves are calculated from the Austin-Cohen equation for *daylight* transmission and for three different values of the absorption coefficient. It is evident that night absorption follows a different law from daylight absorption because the dashed curve crosses two of the dotted curves. This is further verified by Figure 23, wherein the absorption coefficient is plotted against distance for day and night observations. It will be seen that the night values follow a different law from the constant daylight values.

It is to be noted that the data based on the scout cruiser trials and the test between Boston and New York has reference only to receiving with heterodyne from spark transmitters. When sustained waves are used the sensitiveness of the receiving apparatus is further and greatly increased, and the signals have a perfect flutelike note of any frequency the operator may prefer, yet static is not amplified by the apparatus. A still more effective type of the receiver is being worked on, and shows great promise, but even in the form described, this invention of Professor Fessenden bids fair to work a revolution in radio communication.

SUMMARY: Detectors are classified as of the relay or of the transformer type. Relay detectors are arranged so that the energy for the indicator response comes from a local source of energy at the receiving station. Transformer detectors utilise the received energy for producing the indicator response. The need of an amplifying transformer type detector, which selectively neglects static, is mentioned. The basis of the heterodyne receiver, namely, the audible beats produced by the interference of two vibrations of inaudible (radio) frequency received on a nonpolarized receiver, is then fully considered. The development of the heterodyne receiver, its circuit arrangements, and the apparatus employed are described in detail. The use of the heterodyne in the Arlington-Salem tests and the results obtained are given.

DISCUSSION.

ROBERT H. MARRIOTT: How can you arrange to receive radiotelephone messages with the heterodyne receiver?

JOHN L. HOGAN, Jr.: We bring the beats at the receiving station to a point above audibility.

EMIL J. SIMON: What form of sustained wave generator was used in the Boston and Arlington tests?

JOHN L. HOGAN, Jr.: The arc was used in both these tests.

JULIAN BARTH: What arrangements were made in the Arlington tests to permit rapidly following changes of wave length of the transmitting station?

JOHN L. HOGAN, Jr.: The heterodyne receiving set was directly calibrated in wave lengths, and was very easily manipulated for tuning.

GUY HILL: I regard the tests between Boston and Brooklyn as very remarkable, and have personally witnessed such results as Mr. Hogan describes. It is certainly notworthy that spark signals can be amplified to so marked an extent by the heterodyne receiver.

JULIUS WEINBERGER: Has the heterodyne receiver been used with damped wave trains at the receiving station, generated, for example, by the use of the usual buzzer circuit?

JOHN L. HOGAN, Jr.: It has been so employed, but the amplification is not large and the tone is impure.

DR. LOUIS COHEN (by letter): As a matter of record, and in the interests of historical accuracy, it is desirable to give a brief history of the development of the heterodyne receiver. About 1907 or 1908, Professor Fessenden conceived the splendid idea of utilizing the best phenomena for the amplification of radio signals, and also for the elimination of interference. Essentially the operation of the heterodyne is as follows: We superimpose on the incoming signal another current from a local source, of a slightly different frequency; and the operation of the detector is determined by the resultant of the two currents, which gives a current of variable amplitude. If I_1 is the incoming current, I_2 the local current, ω_1 and ω_2 their "angular velocities" (2 π times their frequencies), β the difference of their angular velocities, and φ_t a variable angle, the resultant current can be written in the form:

$$I = \sqrt{I_1^2 + I_2^2 + 2 I_1 I_2 \cos \beta t} \cos (\omega_1 t + \varphi_t). \qquad (1)$$

If the response of the indicating instrument is proportional to the square of the current, as in the case of an electrodynamometer,

the response of the instrument is given by the product of a constant and the square of the value of I above. As a detecting instrument, Professor Fessenden used an electrodynamometer telephone or an electrostatic telephone. The latter was found to be far more sensitive, and is generally used now.

From equation (1) above, it can be readily seen that the variable part of the amplitude of the force is proportional to the products of the currents I_1 and I_2, hence the amplifications may be considerable. Furthermore, if the value of the beat frequency is above three thousand or so, that note will be above the limit of practical audibility; consequently signals differing in frequency by only a few per cent. from that of the local current will not be heard in the telephone.

Professor Fessenden in all his experiments used only persistent oscillations. In fact, he used radio frequency alternators giving slightly different frequencies, one at the transmitting and the other at the receiving station.

On taking charge of the research department of the National Electric Signaling Company, this work was turned over to me for further development. The idea suggested itself that it was possible to use the same principle for the reception of spark signals, and that, employing the arc as a local source of radio frequency currents, amplification could be obtained. This would give a more flexible and adaptable system. In carrying on this work on the heterodyne, I had the able assistance of Messrs. Forbes, Lee, and Van Dyck.

The principle utilized in the amplification of the damped oscillations is practically the same as in the case of sustained oscillations. Using the same symbols as before, with the addition of a, the damping factor of the incoming signal, we have

$$I = \sqrt{I_1^2 \varepsilon^{-2at} + 2 I_1 I_2 \varepsilon^{-at} \cos \beta t + I_2^2 \cos (\omega_1 t + \varphi_t)} \quad (2)$$

Since I_1 is generally small in comparison with I_2, we neglect the first term under the radical, and thus get a periodic force, acting on the receiver, of the beat frequency $n = \frac{\beta}{2\pi}$ and damping factor a. If the damping is not large we shall have partial beat formation. The beats are not so distinct, and the note is not so pure as in the case of the interaction of sustained oscillations, but we do get a note which is independent of the spark note and which can be varied at will by altering the frequency of the

local source. The practical difficulty which arises is that slight variations in I_2, the current from the local source cause considerable disturbances in the telephones because the local current is large compared with the received current. A special arc giving a pure sine wave, and working quietly was therefore devised, and before I left the Company the heterodyne receiver working between Boston and Brooklyn was giving very good results.

While the arc was being developed, experiments were also carried on to determine the best sensitiveness of the herodyne, the most suitable detector, design of apparatus, and various other special details, which can not be adequately discussed here.

It may be noted here that, since the force acting on the electrostatic telephone is proportional to the square of the *voltage,* it must vary inversely with the (frequency) ^{2} for a given current thru the telephone (which is merely a capacity); hence the lower the frequency the greater the sensitiveness. For short wave lengths, the electrostatic telephone is therefore not suitable, but for wave lengths of 3,000 meters and more it compares favorably with the most sensitive receivers.

Finally, it may be mentioned that the heterodyne principle may be applied in connection with any of the common types of rectifying detectors, but in that case, while considerable amplification is obtained, no beat formations occurs. The reason is the following. In the case of the electrostatic telephone the response is proportional to the maximum force acting on it, while the rectifying detector depends for its action on the integrated effect of the square of the current. We shall have then for the force

$$F = \int_0^\infty I_1 I_2 \varepsilon^{-2at} \cos \beta t \, dt.$$

If we put $\beta = 0$, which means equality of frequencies of incoming and local currents, the effect will be proportional to $I_1 I_2$, and we shall have an amplification in the ratio of $\frac{I_2}{I_1}$.

Mr. Van Dyck carried on some experiments at Brant Rock at my suggestion, receiving signals from the New York Herald station on a crystal detector and amplifying them by means of an arc circuit in accordance with the heterodyne principle. He has found that under favorable conditions we may get an amplification of twenty to fifty times.

H. E. HALLBORG (by letter): Mr. Hogan has ably shown that the theory of beats is as important relative to the

heterodyne receiver as the theory of resonance is to coupled circuits in general. The beat phenomena are well illustrated in the paralleling of two alternators. The synchronising lamps flicker rapidly when the frequencies of the machines are widely different, but the lamps may either glow with great brightness, be quite dark, or glow with any intermediate brilliancy (depending on the permanent phase relation between the currents produced by the two machines) when the frequencies are the same. Interesting permanent records of such beat phenomena could easily be obtained by the oscillograph.

During the first tests between the Scout Cruisers "Salem" and "Birmingham" in 1910, I was in charge of the transmitting apparatus at Brant Rock. When receiving from the ships on the 3,750 meter wave, Mr. G. W. Lee, the Chief Operator, always insisted on my starting the radio frequency alternator (100,000 cycles). It was run on open circuit, but with the field excited. A marked increase in audibility at this wave length was thus attained. The beats in this case were in the neighborhood of 20,000 per second, and therefore above audibility. It is interesting to note that the circuit conditions were those which the Company has now found to be the best, replacing the static telephone arrangement. Pressure of routine work at that time prevented further investigations, and it remained for the engineers of the Company to complete the development of the apparatus at a much later date.

The heterodyne, when worked with sustained oscillations, naturally gives considerable freedom from tapping of messages by the amateur. However, until a much simpler and more reliable method of generating radio frequency currents than the present arc or alternator is devised, the heterodyne system will be a shore station equipment, particularly adapted for working at fixed wave lengths. The elements of the circuits have to be so simplified that an experienced engineer is not an essential feature of each installation. For the present, at least, it seems to me that its sphere of usefulness is practically limited to large shore installations.

MR. JOHN L. HOGAN, Jr. (by letter): The discussions by Dr. Cohen and Mr. Hallborg are of distinct interest in connection with the commercial development of the heterodyne. I can confirm Mr. Hallborg's comments concerning reception from the U. S. S. Birmingham and Salem spark transmitters early in

1910, and remember very well an occasion on which the frequencies of the local alternator and the ship transmitter were so nearly alike that audible beats were produced in the telephones of the usual liquid rectifier receiver. The heterodyne is much more suitable for commercial radio signaling than when either Mr. Hallborg or Dr. Cohen were familiar with it, and is not limited in its use either to fixed wave lengths or to shore stations.

Inasmuch as some of the dates and conclusions given by Dr. Cohen cannot be considered in agreement with facts, I am taking the liberty of correcting his two most essential errors. Professor Fessenden's conception of the heterodyne principle dates back at least to 1902, since the receiver of Figure 7 in my paper is shown in his U. S. patent 706,740 issued on August 12th of that year. In the apparatus using a local oscillation generator in combination with a standard rectifier receiver electrical beats are produced and utilized. That this is a fact may be proved by noting that the apparatus is effective for aural reception of sustained waves and that the audio frequency produced is equal to the difference in the fundamental oscillation frequencies.

The heterodyne is still the subject of rigid research, and its progress has been based upon interpretation and understanding of physical facts observed under differing conditions, rather than on any isolated suggestions of a single investigator. The maximum of credit is due to Professor Fessenden, for he made the fundamental invention compared to which the improvements brought out by such of us as have continued the work are indeed small.

Volume I Part 4

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In closing the first volume of the Proceedings of the Institute of Radio Engineers, the Editor wishes to extend to the contributors of papers the thanks of the Institute for their valuable co-operation.

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THE MULTITONE SYSTEM.

By Dr. Hans Rein.

In an earlier article[1], I have shown the connection between freedom from interference with communication in radio telegraphy and the use of transmitting sets which send out signals having the quality of a musical tone. Even were this point alone considered, such systems as employed not merely a single note but a series of definitely chosen notes would be regarded as superior. As compared with the usual quenched sets, the "Multitone" sets have another feature wherein they are more desirable. The production of the musical tone should be independent of the characteristics of the source of electrical energy, and also of the constants of the radio frequency circuits. In this respect, the method of transmission which I worked out in the laboratories of the C. Lorenz Company of Berlin is the most general solution of the problem so far obtained. By the use of this method, as many tones as may be desired can be simply and easily produced. Furthermore, any influence on the pitch of the musical tone by the source of electrical energy or by the radio frequency circuits is completely avoided. The electrical behaviour of such sets may now be considered in greater detail, in connection with a number of illustrative diagrams and photographs.

A. THE PRODUCTION OF THE RADIO FREQUENCY ENERGY.

One of the most important requirements of all modern radio telegraphic equipments is that they shall permit the radiation from the antenna of electromagnetic waves of a single frequency, appreciably that of the free electrical vibration of the open or radiating system. Up to the present, there have appeared two practically satisfactory solutions of the problem. The first method consists in placing a Poulsen arc directly in the antenna, thereby exciting the antenna in its own period.

(1) Rein, Physikalische Zeitschrift, XI., 1910, page 591.

The second method depends on the principle of electrical impulse excitation, which was first theoretically predicted and experimentally demonstrated by Wien[2]. It is the electric analogue of the mechanical phenomena observed with coupled sympathetic pendula, providing one of them is uncoupled from the other at the moment that its amplitude of vibration passes through the value zero.

The following method for the production of radiation of single frequency depends on a type of impulse excitation, which, in contradistinction to that previously mentioned, may be characterized as "ideal" or "perfect." In this connection, the idea arises that the discharges between the electrodes may be considered as simple spark phenomena; but we shall see later that this assumption requires amplification.

Referring to Figure 1; if a source of direct current, E is connected to a condenser C_1, parallel to which is connected a discharge gap, under certain circumstances this system will function as a current transformer, which converts weak currents at high potentials into powerful currents at lower potentials. Such an effect will be produced only when the rate at which the condenser is charged is less than the rate of discharge. If this latter condition is fulfilled, a series of current impulses will be obtained in circuit II. The number of such impulses per second is determined by the time required for the voltage across the capacity, after a condenser discharge, to rise anew to the value required for a discharge across the gap; that is, to the sparking potential. In general, the number of discharges per second increases as the rates of charge and discharge approach equality.

The exact course of the discharge in the radio frequency circuit and the resulting effects are dependent on a number of factors, the influence of which will be given. They are:

(1) The shape, material, and temperature of the discharge, and the separation of the electrodes.

(2) The values of the capacity and inductance in the radio frequency circuit which is connected to the gap, and of any further radio frequency circuits which may be coupled to the former.

(3) The method of supplying energy to the gap.

(2) M. Wien, Physikalische Zeitschrift V., 1906, page 871.

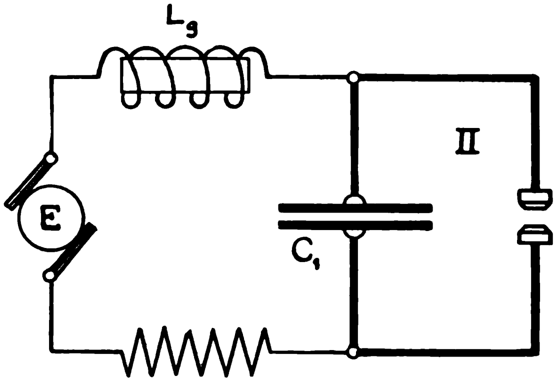


Fig. 1

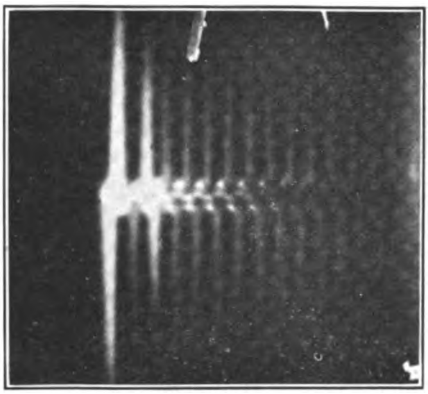


Figure 2

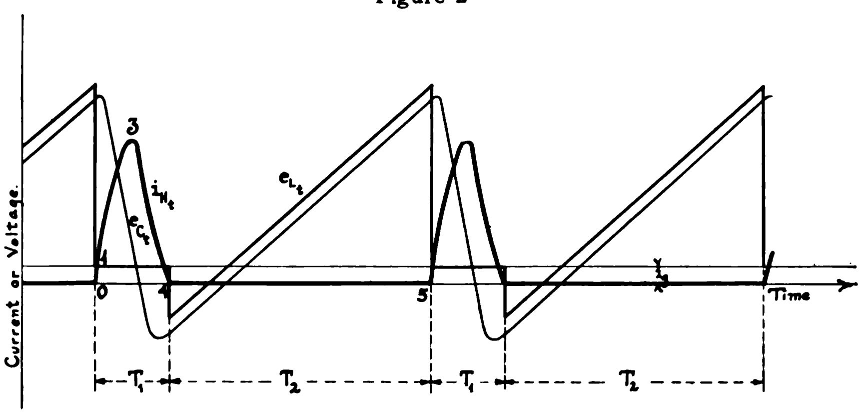


Fig. 3

(1) THE GAP DISCHARGER. The type of gap discharger used in the Multitone system was worked out by Scheller[3]. It consists of an approximately hemispherical piece which fits into a hollow hemisphere, the two parts being separated by a small distance, and the discharge taking place, as in the Poulsen arc, in an atmosphere of continually renewed vaporized alcohol. The peculiar properties of this gap depend on the fact that, when the discharge passes between two electrodes which are separated by a small distance (less than 1. mm.), ionisation (and consequent conductivity) of the gap very rapidly disappear. Wien was the first to make use of this property of short gap dischargers, in his method of impulse excitation involving the usual beat phenomena. The spark ceased at the moment when the entire energy of the primary circuit had been transmitted to the antenna. In the radiating system, a current having the natural period of that system will persist until all the stored electrical energy has been radiated or dissipated as heat. In this case, we are obviously dealing with a system wherein the source of direct or alternating current energy is, in effect, disconnected from the radio frequency circuits until the electrical disturbances in that circuit have entirely disappeared. Monasch[4] has employed the same gap discharger for the production of another phenomenon, namely the excitation of sustained alternating current in the radio frequency circuit. It is easy to see how the same means were employed by two independent workers for the production of particular types of electric currents.

To obtain the quenching action in the gap discharger reliably, some of a number of particular methods of construction of the gap must be used. Thus, the use of metal electrodes is to be recommended exclusively, because they readily conduct away the heat; and it is further possible (following the suggestion of H. Th. Simon) to cool them by flowing water. All methods of insuring a uniform distribution of the successive sparks over the sparking surface are especially advantageous, because in this case the spark always passes at a new and cool point. Lepel[5] obtains this wandering of the spark by sep-

(3) Scheller, German Patent, No. 237,714.

(4) Monasch, German Patent, No. 193,328.

(5) C. v. Lepel German Patent, No. 232,174.

arating the electrodes by a sheet of paper of proper thickness. the presence of the paper causing the spark slowly to travel out from the center, thereby gradually burning up the paper. In Brown's gap discharger , one of the electrodes is kept in rotation; a method which had previously been successfully employed by Tesla. Furthermore. a rapid de-ionisation of the gap can be caused by a stream of gas (due to Thomson), or by a deflecting magnet (Tesla). The reliability of operation of such gaps is increased by air-tightness, the exclusion of oxygen, the employment of an atmosphere of hydrogen, or the introduction of other gases or non-conducting liquids.

To summarise, we may say that it has been established that all these discharges have the common property that the spark passes within the "critical zone," and that by one or the other of the means mentioned the quenching action is increasd in certainty. It is of importance—and attention has already been called to this—that the same types of charge and discharge currents can be obtained in a given gap, and may give the discharge the character of a spark or an arc. The type of discharge is determined solely by the electrical constants of the circuits, the closeness of coupling, and the method of supplying energy to the discharger.

(2) THE EFFECT OF THE ELECTRICAL CONSTANTS. If it is desired to produce in circuit II. (Figure 1) a rapid succession of damped oscillatory discharges, as represented in Figure 2, the decrement of this circuit, (d_1) must have a suitable value. In any case the decrement is given by the equation:

$$d_1 = \frac{1}{150} \cdot \frac{C_1 \ R}{\lambda_1}$$

where C_1 is expressed in cm., R in ohms and λ_1 in meters. At constant wave length λ_1, and approximately constant resistance R, the damping increases directly with the capacity C_1. The available energy per second is given by

$$W = N \cdot \frac{e_z^2 \ C_1}{2}$$

where N is the spark frequency, and e_z the sparking potential.*

(6) Brown, The Electrician, Vol. 58, 1906, page 201.

*The notation is that recommended by the Committee on Standardization of The Institute of Radio Engineers.

The value of N increases as

(a) the generator voltage E is increased, provided the sparking potential and primary capacity are kept constant,

(b) the sparking potential e_z is diminished, keeping the generator voltage and impulse circuit capacity C_1 constant,

(c) the capacity C_1 is diminished, keeping e_z and E constant.

(d) The choke-coil L_g (Figure 1) has a marked influence on the spark frequency, because it partly determines the time of charging. If this inductance possesses a sufficiently large value, the energy stored in it, namely, $\frac{L_g \, i_g^2}{2}$, is sufficient to charge the capacity nearly fully. In that case, after the sudden quenching of the spark, the next charging of the capacity to any desired voltage takes place in an extremely short time. Hereby the character of the discharge in circuit II is completely altered, particularly if the capacity C^1 has been much increased at the expense of the inductance L_1, thereby causing an increase in the decrement, d_1. The current and voltage curves then take forms which have also been observed with the Poulsen arc, when it is producing oscillations of the second class (this being the case in which the amplitude of the alternating current is greater than that of the direct current). Such curves are shown in Figure 3, where i_g is the direct current, i_{Hg} the arc current, e_{C_t} the voltage across the capacity C_1, and e_{I_t} the voltage across the arc.

It will be seen that current through the gap discharger starts at the point O, then rises to the point 1 during which rise the current is entirely supplied by the direct current i_g. Thereafter the current produced by the discharge of the capacity C_1 is added to it. The arc current attains its highest value at the point 3, after which it steadily decreases, until, after reaching the point 4, for a short time no current passes between the electrodes. Under proper circumstances, this short time suffices properly to distribute the electrical energy for the next discharge. The direct current i_g, which has maintained a constant value, charges the condenser until its plates reach a difference of potential equal to the sparking potential, this corresponding to point 5.

The system operates in this fashion only when a marked quenching power is inherent in the gap used, and when the damping of the impulse circuit is of proper magnitude. Otherwise, after the point of zero current is reached, the voltage across the gap discharger will produce a discharge in the reverse direction.

There will therefore be in the primary circuit a regular succession of current impulses, which, through the intervention of a transformer, charge the antenna capacity. After the electrical disturbances in circuit II cease, the energy in the antenna is gradually converted into heat and electromagnetic radiation. The wave length of the radiated energy is naturally solely determined by the electrical constants of the radiating system in this case.

In order to obtain a clear idea of the voltage and current relations, and the interaction of the impulse and antenna circuits, the current curves were made by the use of a sliding plate oscillograph. By an appropriate increase in both capacity and inductance (keeping their ratio constant, however), the frequency of each of the circuits was so diminished that the oscillograph reproduced the curves faultlessly.

The conclusions drawn from the curves obtained are as follows: Considering the current through the spark gap (Figure 4), or in the primary circuit (Figure 5), it is seen that there are rapid series of current impulses. Each of these produces in the closely coupled antenna a train of waning waves (Figure 6). It is worthy of note in connection with this process (perfect impulse excitation), that the impulse circuit and the antenna need not be tuned to each other. Proof of this is furnished by Figure 6, which shows the current curves for two antennae, both of which were coupled to the same impulse circuit and excited thereby. However, in order to obtain an efficient energy transfer, it is not desirable to tune the two radio frequency circuits to very widely different frequencies. If a receiving arrangement employing a contact detector and telephone is used, the signals will not be heard because the number of wave trains per second is of the order of magnitude of 10,000 or 20,000.

A comparison of the arrangement described with those employed in some of the systems in common use establishes the following facts. When an oscillator and a resonator are

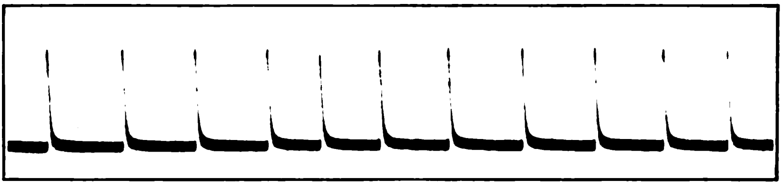


Figure 4

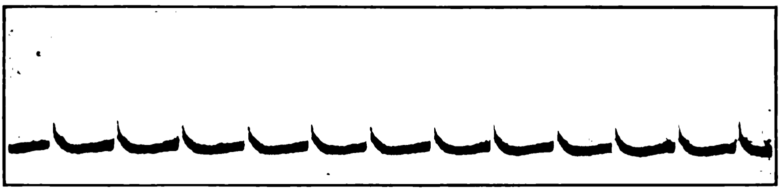


Figure 5

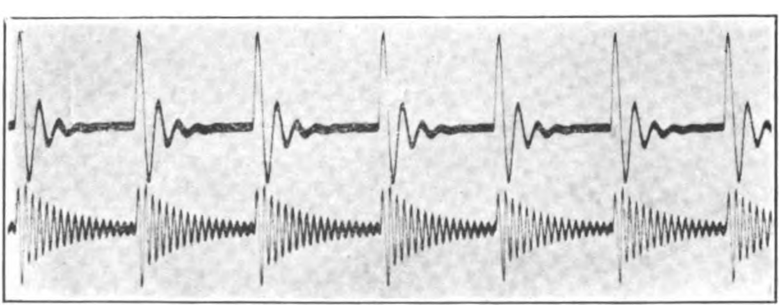


Figure 6

coupled in the usual way, there appear in each of these circuits two waves, which lie respectively above and below the free wave of each system. When Wien's method of impulse excitation is used, and the circuits are not sharply tuned, there appear three waves, and with proper tuning one wave. For the case of ideal impulse excitation, as described, the antenna vibrates *in all cases* with one wave, namely, that of its natural frequency.

An examination of the results obtained so far, shows that the process of ideal impulse excitation resembles the process of the production of oscillations of the second type with the Poulsen arc. Such currents are characterized by a very large ratio of the time during which no current flows through the gap discharger to the time during which the capacity is discharging itself across that gap. It is because of this that the necessity for sharp tuning of the primary circuit to the antenna is removed, and that in spite of very close coupling only vibrations of a single frequency are produced in the antenna.

B. THE MODULATION OF THE RADIO FREQUENCY ENERGY TO A CHOSEN WAVE FORM.

In order to appreciate the peculiar method of operation of the arrangement for the production of the note, an historical development of the method will be of advantage. The discovery of the Poulsen arc provided a system which furnished greater possibility of sharp tuning than any previous method. It seemed capable of improvement only in that a musical tone in the receiving set was missing. Because of this, some time ago Poulsen himself described means for radiating the energy in the form of rhythmical pulses, that is, at a definite pitch [7]. All of his methods involved periodically varying the antenna current by means of interrupters, or rotating condensers or variometers. Inasmuch as no arrangement satisfactory for practical purposes was thus achieved, the C. Lorenz Company of Berlin carried out a successful research intended to attain this end by other means.[8] One of the methods used was intended to impress a periodic variation of amplitude on the

(7) V. Poulsen German Patent. No. 207,159.

(8) H. Rein, Der Radiotelegraphische Gleichstromtonsender, Langensalza, 1912.

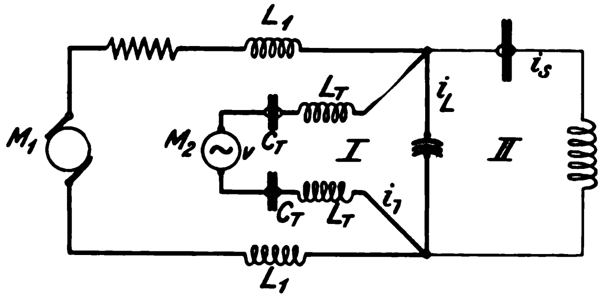


Fig. 7

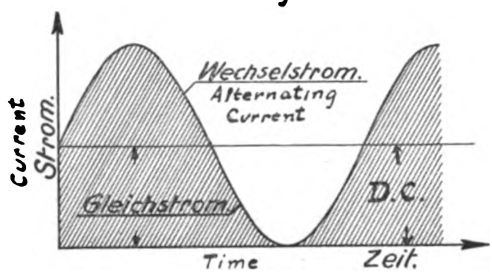


Fig. 8

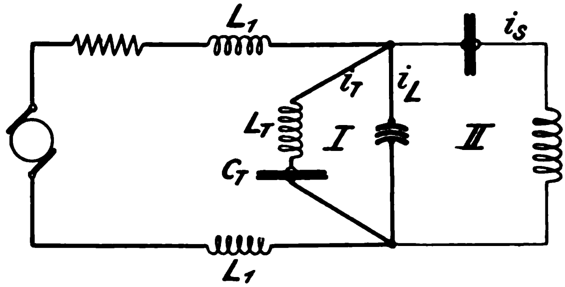


Fig. 9

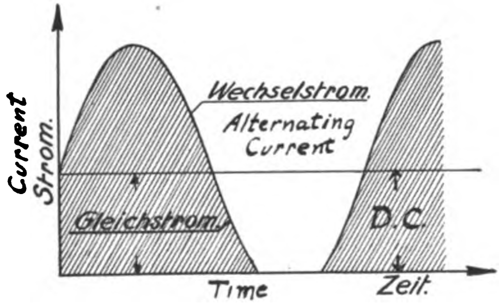


Fig. 10

energy obtained from a Poulsen arc by connecting it not only to the direct current generator M_1 (Figure 7), but also to an alternator M_2 of about 500 cycles. Figure 8 shows how, because of the effect of the pulsating direct current (represented by the cross-sectioned areas), the amplitude curve of the radio frequency current is similarly periodic.[9]

The choke coils L_1 prevent the current from the alternator passing through the direct current generator, while the "blocking" condensers C_T prevent the direct current from passing through the alternator. It is found with this arrangement that a reliable operation of the apparatus is obtained only when the frequency of n of the generator M^2 is the same as that of the free or resonant vibration of the circuit I that is, when the effective capacity and inductance combine to a zero reactance at that frequency. It will be noted that the direct current generator will then supply the actual energy, whereas the alternator will control the tone. Advancing a step beyond this arrangement, it is seen that the assumption is valid that nothing will be altered by the omission of the alternator M_2, and connecting together the wires from the condensers C_T formerly leading to the alternator.[10] Experiment verifies this conclusion, as will be seen below. Simple as this arrangement seems, if a Poulsen generator be used as the gap discharger, it is found not to be sufficiently certain in operation. The reason for this, as shown in Figure 10, is that after each alternating current impulse, in consequence of powerful deionisation, the arc is extinguished; and if the period of zero current flow is increased too much the discharge cannot start again unless the electrodes are approached to each other. Therefore the Poulsen arc could not be used, and a new type of discharger had to be devised which permitted the discharge to pass readily at the voltages available with consequent production of radio frequency currents. This discharger, which was designed from this new point of view, has already been described.

In order to give the radio frequency energy the periodicity of a musical tone; in accordance with the researches of Thomson and Duddell with singing arcs, another circuit I (Figure

(9) C. Lorenz Company, German Patent, No. 229,219.

(10) C. Lorenz Company, German Patent, No. 249,400. E. Nesper. Helios, Number 21, 1911.

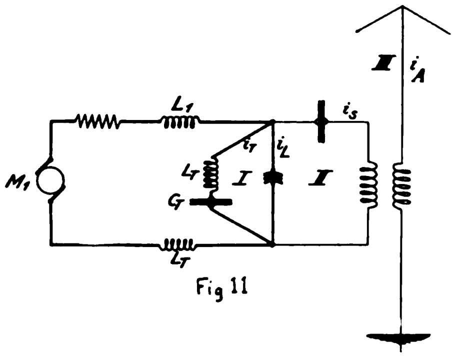


Fig 11

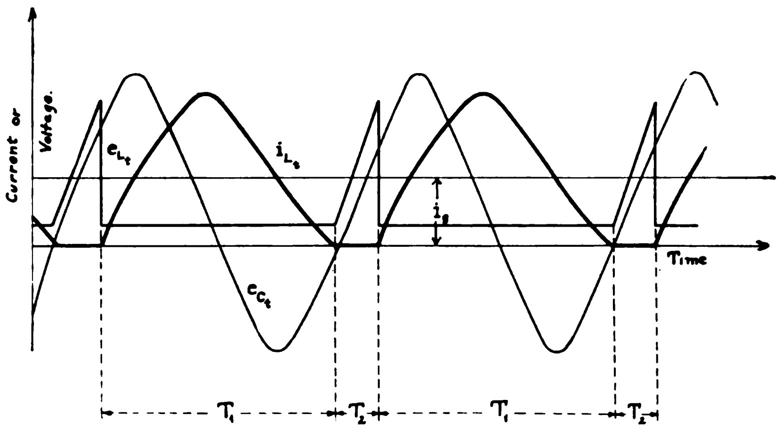


Fig. 12

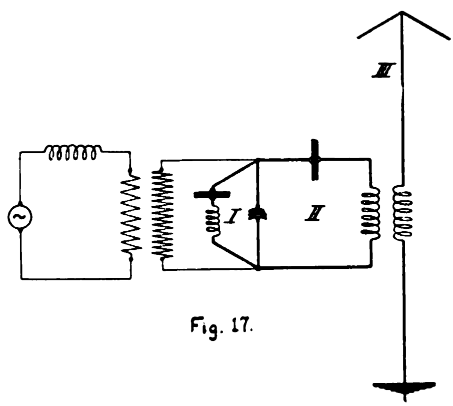


Fig. 17.

11) was placed parallel to the arc. The inductance and capacity of this circuit were so chosen that the natural frequency of the circuit falls within the range of audible musical notes. The effects observed in this circuit are practically the same as those observed in the impulse circuit II. In this case also the theory of the arc gives correct laws governing the forms of the current and voltage curves. These are shown in Figure 12, wherein i is the direct current, i_{L_t} the arc current, e_{C_t} the voltage across the capacity, and e_{L_t} the voltage across the arc. Just as in the impulse circuit II, current impulses of constant amplitude are present in the tone circuit I. The phenomena in the two circuits differ only in so far as the difference of the ratio of capacity to inductance in the two circuits may affect them. To produce large amounts of energy in the radio frequency circuit II the capacity in it must be increased at the expense of the inductance. The process is limited by the necessity of having sufficient inductance to couple closely to the antenna circuit. High damping of the individual current pulses together with properly chosen pauses between them prevent resonance phenomena in the system, and this is requsite for single frequency radiation. In spite of the large currents which then flow, the gap is not injured, because the pauses between the individual impulses are sufficiently long to permit complete de-ionisation.

The relations in the tone circuit are quite different. Here oscillations capable of giving marked resonance effects are desired; and the period of zero current thru the discharger is to be as short as possible. And the energy supplied should be only sufficient to furnish a reliable control of the discharges across the gap. These requirements lead to a small damping of the tone circuit, and a large inductance together with a small capacity. The eventual limitation of the process arises from the engineering necessity of preventing fusion of the slightly separated electrodes, and this becomes increasingly difficult as the current is increased.

The accompanying oscillograms (Figures 13 and 14) show how the impulse circuit and the tone circuit operate in conjunction. These oscillograms were made under the same conditions as those already shown. Figure 14 shows the influence of the two circuits connected across the gap on each other, and Figure 15 pictures the processes taking place in the antenna.

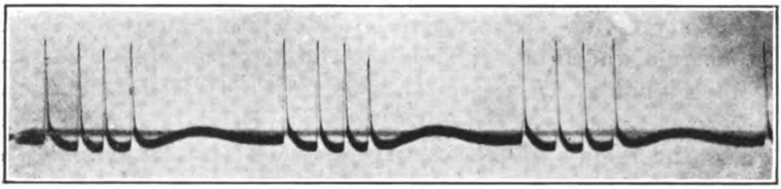


Figure 13

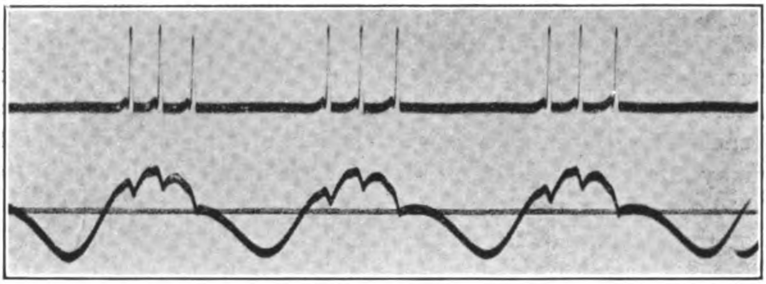


Figure 14

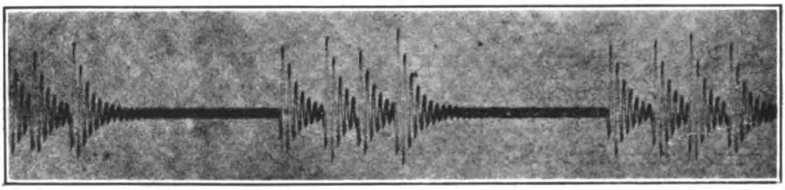


Figure 15

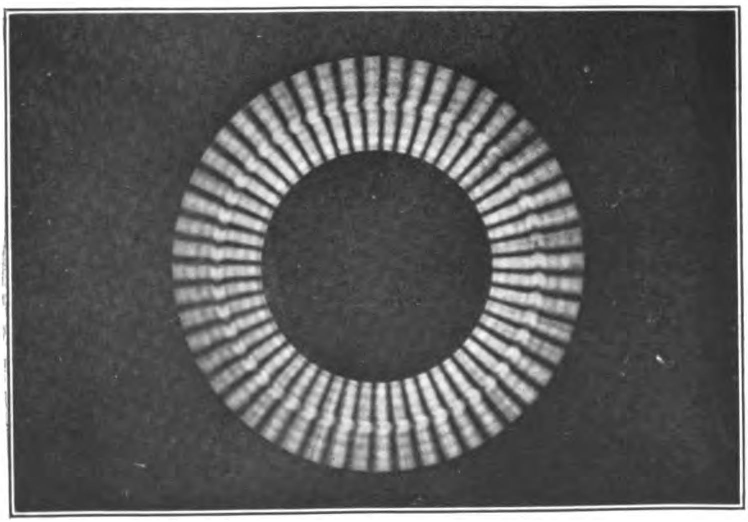


Figure 16

The trains of waves emitted from the antenna will then be heard in the receiving telephone as a musical note. If a rotating helium tube be connected in a circuit which is coupled to the antenna, so soon as the tone circuit is closed the helium tube appears as a star of light, each ray corresponding to a single wave train (or partial discharge).

It has been tactily assumed that a direct current machine was the source of energy for this type of transmitter. Since the available radio frequency energy depends on the capacity in the impulse circuit, the sparking potential, and the number of impulses per second, it can be increased only by increasing one of these factors. If one considers that the spark frequency is limited by the type of gap which is used, and that the capacity in the impulse circuit must have a value appropriate to the wave length employed, it will be seen that increase in radiated energy can be attained only by an increase in sparking potential. Therefore, for stations of large range, the source of energy is a low frequency alternator (15 to 50 cycle), and the voltage is raised as far as may be desired by the use of a transformer (Figure 17).[11]

The effects obtained differ only slightly from those with direct current, and the more nearly the alternating current wave form is rectangular in form, the less the difference. If the curve is more peaked, in consequence of the slow alternations, the tone in the receiving station will resemble that of a trilling or throbbing flute.

In conclusion, the question may be asked: What marked advantages has this system of transmission? One answer to this question is that a single wave is radiated from the antenna, and that by a mere alteration of the capacity or inductance in the antenna the frequency can be altered without further necessity for tuning. Furthermore, the method permits of thoro utilization of acoustic resonance. With an ever-increasing number of radio telegraphic stations, the problem of the avoidance of interference becomes increasingly difficult to solve. Altho skilled operators can accomplish much with proper apparatus at the present time in tuning and reading thru interference, still acoustic resonance effects are an aid not to be neglected. For, by the use of the mono-

(11) H. Rein, Radiotelegraphisches Praktikum, 2nd Edition, Springer, 1912, page 200.

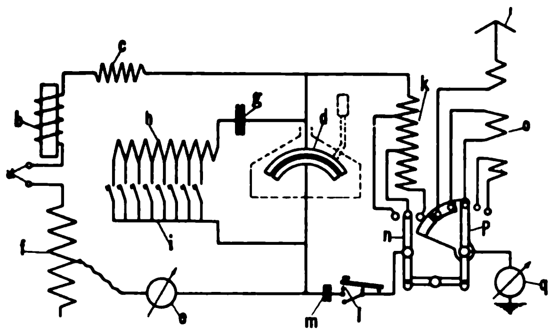


Figure 1

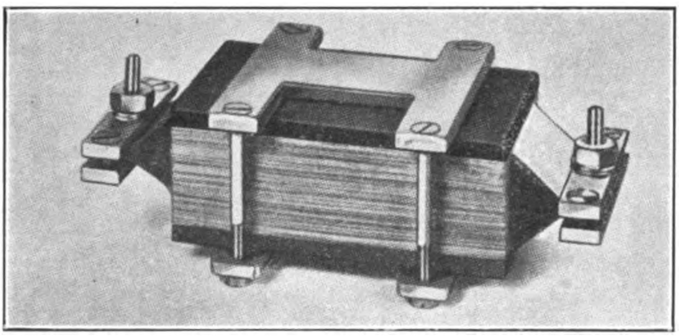


Figure 2

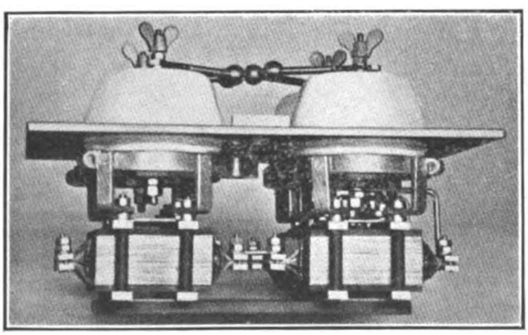


Figure 3

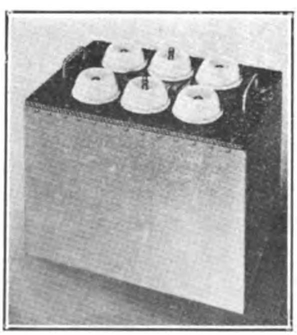


Figure 4

telephone or any other tuned receiver, reception can be restricted to musical notes of a definite pitch. If the inductances or capacities of the tone circuit are arranged so as to be controlled by keys similar to those of a piano keyboard, bugle calls can be readily transmitted, and methods of code transmission unintelligible to interlopers can be readily devised.

(Translated from the German by the Editor.)

ADDENDUM.

Thru the courtesy of the C. Lorenz Company and Dr. Rein, the Editor is enabled to place before the readers of the Proceedings some further information on the practical details of the Multitone System and some illustrations of the apparatus employed.

The principles underlying the Multitone apparatus having been adequately treated in Dr. Rein's paper, we shall restrict ourselves to practical considerations in connection therewith. In Figure 1 are shown the connections of the transmitter set. Here *d* is the connection to the source of high voltage direct or low audio frequency alternating current, *b* a reactance, *c* a fixed resistance, *f* a variable resistance, *e* an ammeter. Passing to the tone circuit, *d* is the Scheller gap discharger, *g* the mica dielectric tone circuit condenser, and *h* a reactance variable in steps. The tone is controlled by depressing one of the keys *i*. In the impulse circuit, *k* is a stepwise-variable inductance, *l* a special key, and *m* a high tension condenser. The antenna *r*, its loading inductance *o*, the hot-wire "radiation ammeter" *q*, and the ground connection are shown to the right. The switch *n*, *p* is so arranged that primary and secondary circuits can be tuned simultaneously by a single adjustment.

Passing to the elements used in making up these circuits, Figure 2 shows the type of condenser which is used in the tone circuits. It consists of sheets of mica as a dielectric between thin sheets of metal, the whole mass being tightly compressed. Such condensers may be mounted in oil when it is desired to use them with still higher voltages; and Figure 3 shows such a condenser taken out of its case. The pro-

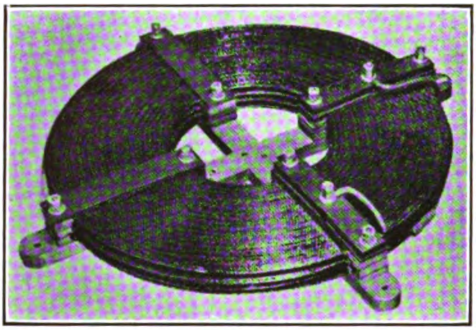


Figure 5

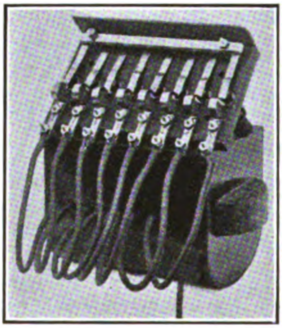


Figure 6

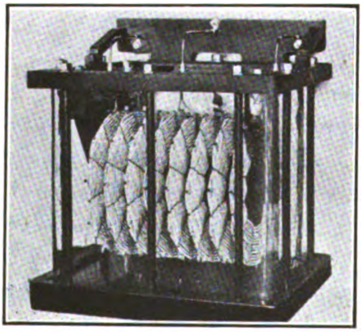


Figure 7

Figure 8

tective gaps above the case, and the peculiar form of leading-in insulator are also shown. In Figure 4, a number of such sections are seen mounted in their case. By means of movable plug connections, any number of sections can be connected in circuits, and thus the tone may be readily varied. The copper condenser box shown in this figure is about 55 cm. long, 40 cm. wide, and 45 cm. long. It contains no less than 40 condenser sections, each of 0.11 μf., and the necessary connections. As regards space efficiency, it is greatly superior to Leyden jars.

A reactance, or "choke coil" for supply circuits is illustrated in Figure 5. It is of the multiple layer spiral type. The containing case of a step-wise variable inductance for the tone circuit is pictured in Figure 6. Above it is the under side of the tone key-board with the section contacts, and the taps running from these contacts to the sections of the inductance.

Figures 7 and 8 show two types of inductances used in the radio frequency circuits. In the type pictured in Figure 7, the spiral coil sections are woven on a series of radial supporting rods fastened to an insulating central piece. Taps are brought from the ends of each coil to a series of jacks on the top of the case, and the whole set of coils mounted in glass case under oil. This type is intended for use with high tensions. The inductance of Figure 8 is continuously variable. It consists essentially of two flat rectangular coils connected in series, each of the coils being then bent on the surface of a cylinder, and one of these coaxial cylinders being rotatable within the other. It is also under oil and intended for use on high tension. Multiply stranded wire ("litzendraht") is used on the inductances.

The construction of the tone-circuit key-board for the larger sets is shown in Figure 9. The white piano keys are intended for use when it is desired rapidly to change the note, whereas the black buttons on the top serve to lock the corresponding piano key in place, permitting sending on a fixed note using the regular transmitting key.

A series of insulators intended especially for radio frequency circuits are shown in Figures 10 and 11. Those of Figure 10 are of the so-called "egg" type, and those of Figure 11 are leading-in insulators. The engineering requirements of

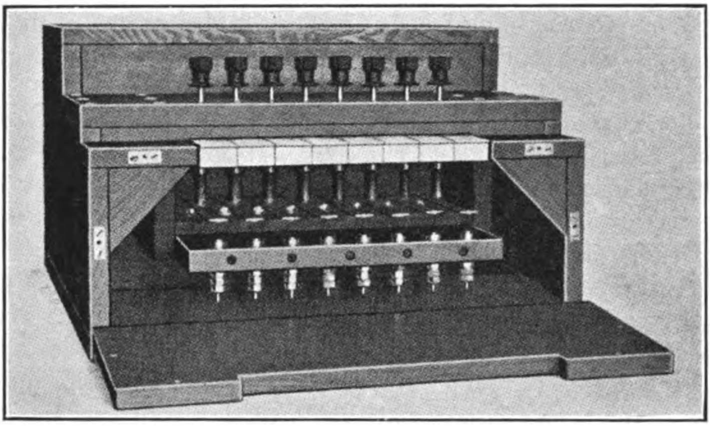


Figure 9

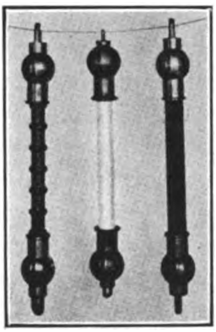


Figure 10

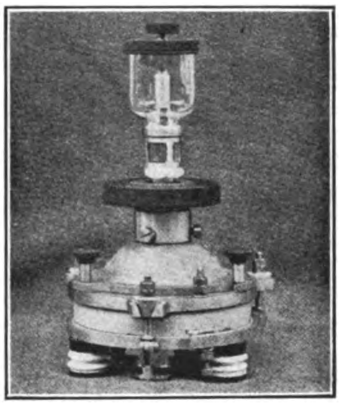


Figure 12

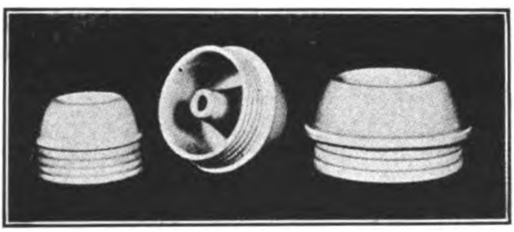


Figure 11

insulation for radio frequency high voltages, namely, long leakage paths over the insulator, and small capacity between the insulated conductors, are well met.

In Figures 12 and 13 are shown the exterior and interior of the simplest form of unit gap discharger. The alcohol feed cup is shown at the top. Below it is the adjusting ring for gap length. The clamps for holding the two halves of the gap together on the large insulating ring, and the porcelain insulating feet are also visible. In Figure 14, the double gap is shown. It differs from the first only in that it consists of two separately adjustable sections, arranged so that the discharge can be readily started. It is used for slightly higher powers than the first form. When it is desired to use higher powers still, alternating current dischargers are employed. These are built with a number of sections in series, as shown in Figure 15, and are arranged for air cooling. A water-cooled double discharger for use with alternating currents and high powers is shown in Figure 16.

It is interesting to note that the ratios of the values of inductance to capacity in the tone circuit and in the radio frequency circuit are widely different. Their actual values (with inductance expressed in microhenrys and capacity in microfarads) are respectively approximately $6(10)^5$ and 12.

The connections of the receiving set are shown in Figure 17. Here *r* is the antenna, *s* a receiver variometer, and *t* a series tuning condenser. The coupling to the antenna circuit is through the coil *u*. The crystal rectifier *v* is shown in Figure 18. It will be seen that it is easily adjusted. Parallel to the telephone receiver may be connected the three condensrs *w*. Each section has a different value. For receiving long waves the halves of the variometer may be connected in series as shown in the left-hand diagram of the Figure 17.

The appearance of the receiving sets is shown in Figures 19 and 20. The first of these is the receiver which is used for small stations. The left-hand handle in the front of the case controls a variable condenser, and simultaneously, through the front gears, controls the tuning variometer and the coupling to the detector circuit. By simply turning the handle, and operating a single switch on the case, it is possible to tune continuously from 200 to 2,000 meters wave length. The type of receiving set used in larger stations is shown in Figure 20.

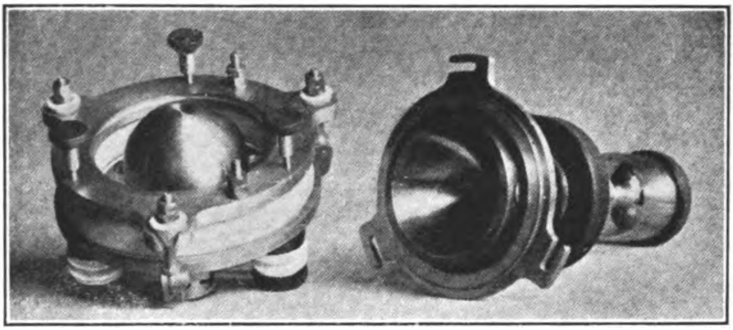


Figure 13

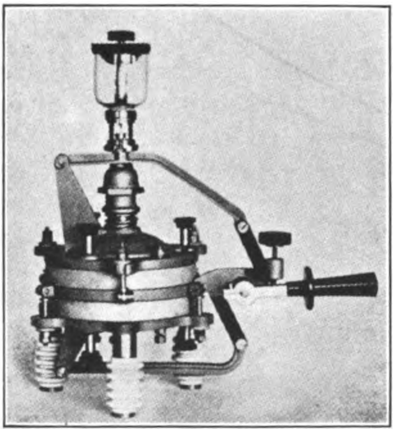


Figure 14

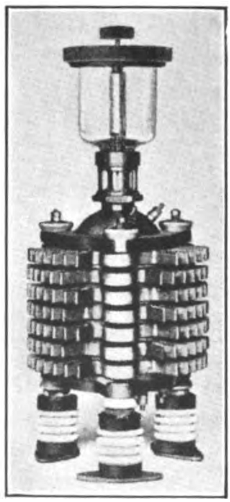


Figure 15

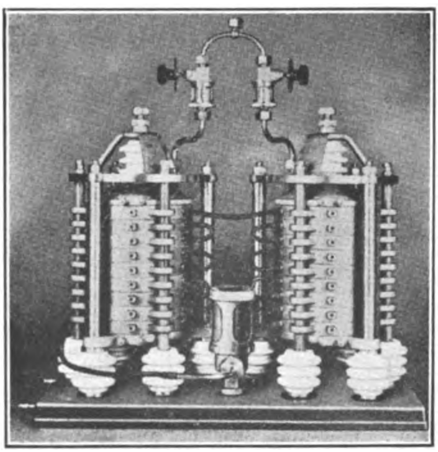


Figure 16

At the top is seen the inductive coupler, the primary of which is controlled in position by means of a special linkage mechanism. The secondary is connected to the main switch. The variable condenser is shown at the left of the base, to the right of which are placed the detector clamps and some small dry batteries for operating a test buzzer.

Passing now to completely assembled sets, the smallest of these is the aero type shown in Figure 21. To the left are prominently seen the tone circuit condenser and the direct current ammeter, in the center the discharger, and to the right the hot wire "radiation ammeter," the antenna coupler, and the control switch, or key. The apparatus is of very small dimensions (the greatest dimension being less than 52 cm. (20″), and the entire weight less than 100 pounds (45 kg.). Another small set, mounted somewhat differently, is shown in Figure 22. The arrangement of parts is quite similar to that previously shown. The Multitone apparatus is very well adapted for military uses. The power plant of a transportable set mounted on a wagon is shown in Figure 23. A water-cooled two-cylinder gas engine is direct-connected to the generator. In Figure 24 can be seen the remainder of the apparatus. The transmitter is arranged to radiate waves between 550 and 2,000 meters. The key-board, which permits choosing rapidly any note between about 500 and 1,200 cycles, is seen in the middle of the figure. The general appearance of an automobile station is given by Figure 25. The antenna used with these sets is of the umbrella type. Special reels are provided for the wire when not in use. A sectional mast which can be rapidly erected to a height of 18 to 25 meters, and which rests on an insulated ground plate, is a portion of the equipment.

Passing to the sets intended for use over longer distances, Figure 26 shows the large direct current set for ranges up to 150 miles (250 km.). It will be noted that the two-section gap is used. The ship sets are arranged in a particularly convenient fashion, the entire set being an integral portion of the operator's desk. Figure 27 illustrates a ship set intended for ranges of 500 to 600 miles (800 to 1,000 km.). The coupling and wave length of the transmitter are controlled by the two handles shown at the left. In the center is the keyboard and the air-cooled discharger. To the right is the receiving set,

behind which the key relay is placed. When a fairly large station is needed, the type of construction shown in Figure 28 is employed. The tone circuit condensers, the two dischargers, the coupler, and the tuning variometer are all visible. All of these larger sets are fed with a low frequency alternating current (e.g. 30 cycle).

DISCUSSION.

DR. J. ERSKINE-MURRAY (by letter): In giving the theory of shock excitation, Dr. Rein has hardly laid sufficient stress on the importance of the form and dimensions of the gap itself. Considerable damping of the primary circuit due to large capacity and close coupling is, of course, useful, but the most important factors are the shape and size of the gaseous section, i.e., of the gap itself. With the usual (capacity)/(inductance) ratio of an ordinary spark set, there is no difficulty in obtaining shock excitation if the gap is short enough and the power small; as Wien indeed found. It is when larger powers, such as are necessary in radio telegraphy, are required that Wien's arrangement is no longer sufficient, and that the form of gap used by Lepel, or something equivalent, becomes essential.

With such a gap, the fact appears to be that the expansion of the gas in the discharge is hindered by its viscosity and constrained by the smallness of the space between the parallel surfaces of the electrodes. The pressure in the hot gas surrounding the spark therefore rises, and remains high for an appreciable time as the pressure wave is not able to escape. The resistance of the gap therefore rises rapidly and checks the passage of further current, i.e., damps the primary current.

Dr. Rein's suggestion that tuning is hardly necessary between primary and secondary is only partially in accordance with the results of other experimenters; Galletti, for instance, has found that the advantage of tuning, even when the primary current impulse is only a single half wave, is by no means negligible. From theory, one would certainly expect that the wave form of the primary current would have some influence on the secondary current induced by it.

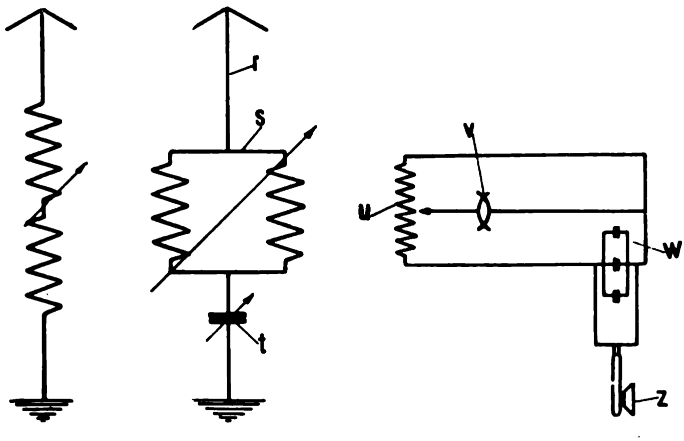


Diagram of the Receiver.
Figure 17

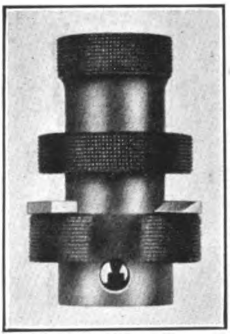


Figure 18

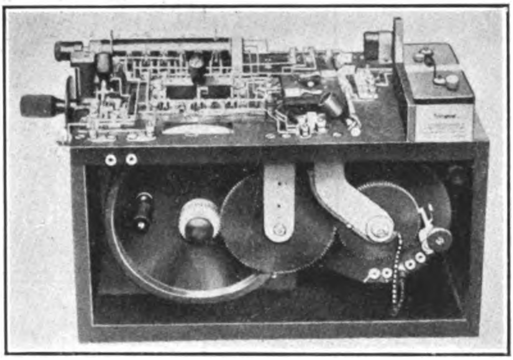


Figure 19

Figure 20

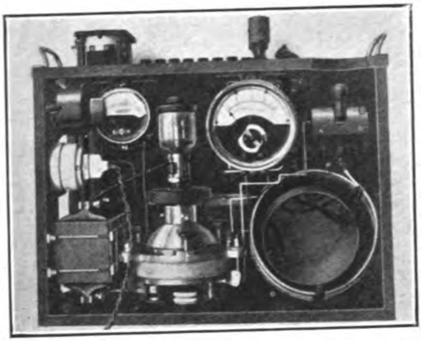


Figure 21

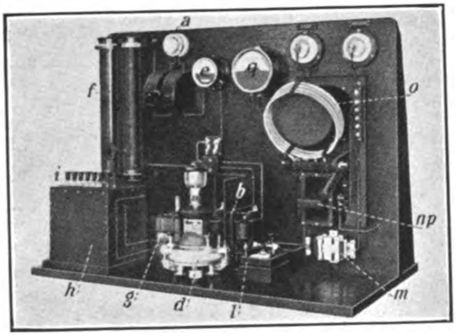


Figure 22

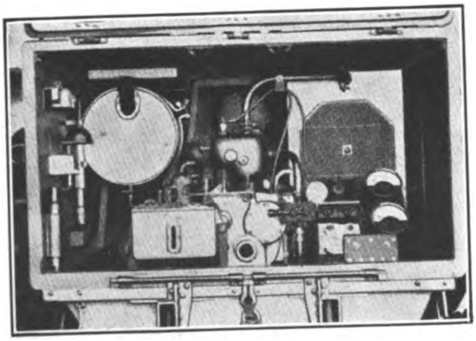


Figure 23

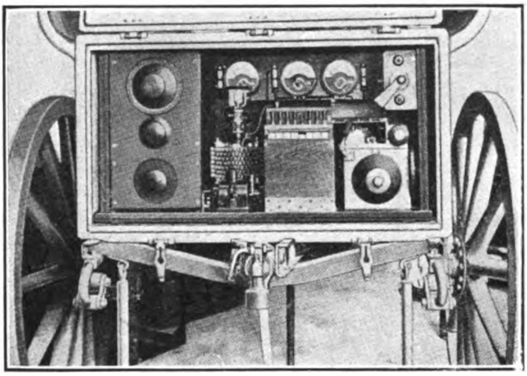


Figure 24

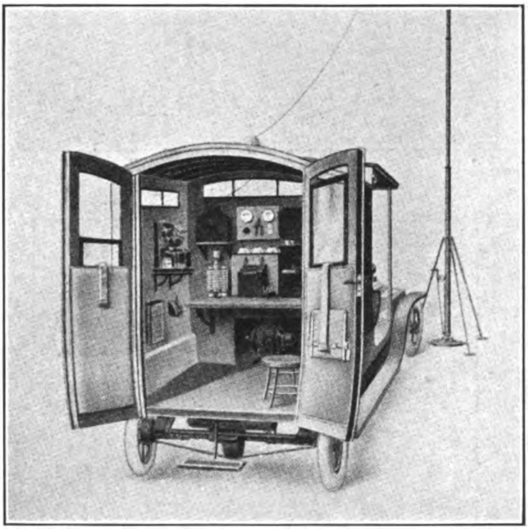


Figure 25

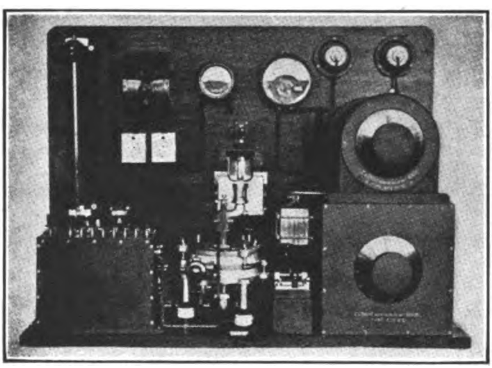


Figure 26

Figure 27

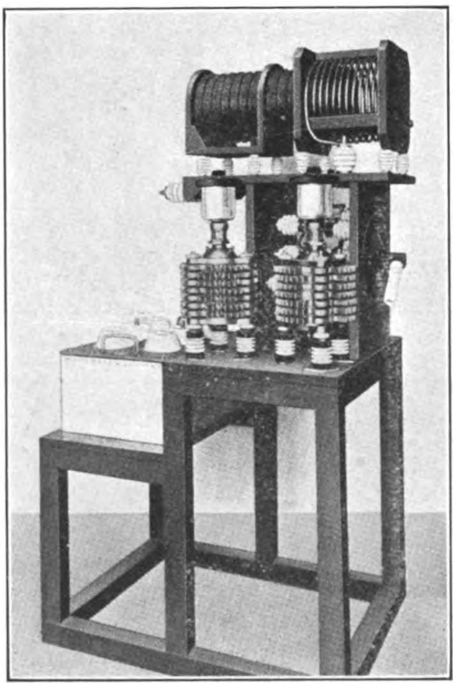


Figure 28

The appearance of three waves in the secondary is not in reality a matter of tuning, as Dr. Rein seems to suggest. Even with exact tuning they appear if the damping of the primary (from all causes, including coupling) is insufficient. The two side humps in the resonance curve represent, in fact, the conditions during the earlier part of the whole phenomenon, namely, the time before the primary is extinguished during which the action is that of an ordinary spark circuit with two waves due to close coupling. When the primary current dies out, the secondary continues to oscillate at its own natural frequency and gives the central peak, or third wave. The condition determining the appearance of three waves is therefore too small a damping in the primary.

The use of various musical tones, which Dr. Rein recommends, is obviously advantageous. I may mention that in the winter of 1909-10 I suggested the use of musical signals, such as bugle calls, when testing the shock excitation system designed by von Lepel and Dr. Burstyn, in which auxiliary circuits having acoustical frequencies were used to control the primary discharge so as to produce musical signals of various pitch.

London, September 11th, 1913.

ALFRED N. GOLDSMITH: There can be, as Dr. Erskine-Murray says, no doubt but that the shape and duration of the primary wave, even in the case of Dr. Rein's "ideal impulse excitation" with a half wave, do exert a marked influence on the secondary energy; or that the maximum secondary energy is uniquely determined by tuning to one or more wave lengths under such conditions. The experience of the Telefunken Company is given in The London Electrician for November 10th, 1911, page 172. It may be objected that "ideal" quenching was not obtained in this case. This objection does not apply to the observations given by Chaffee in the Proceedings of the American Academy of Arts and Sciences, November, 1911, page 267, and also in the Journal of the Franklin Institute, May, 1912, page 437. Chaffee worked with a copper-aluminum "quenched arc" gap in an atmosphere of moist hydrogen, and fed with (constant) direct current. By means of curves drawn from photographs made with a Braun oscillograph, it was conclusively shown that the primary cur-

rent consisted simply of discrete loops. We have, therefore, the conditions of "ideal" impulse excitation. By varying the inductance in the primary or impulse circuit, the duration (and shape) of the current loop was changed, without, however, altering the number of complete secondary oscillations occurring between successive primary discharges. Under these conditions, the secondary current was measured as the primary inductance was altered. I quote from the latter of the articles mentioned above: "In this case the hot-wire ammeter reading was taken in the secondary circuit as an inductance, in series with the primary of the oscillation transformer was varied. . . . A variation of this inductance changes the natural period of the primary circuit, thus affecting the time of duration of the primary impulses without materially changing their frequency. . . . The curve of secondary current shows the marked maximum when, the inverse charge frequency (i.e., the number of complete secondary oscillations between successive primary discharges) remaining constant, the primary discharge loop has the best duration compared to the period of the secondary oscillation. . . . Several measurements were taken of the natural period of the primary circuit when adjusted to give maximum secondary current, for different secondary wave lengths, and it was found that this natural primary period divided by the corresponding secondary period was, in every case, within one or two per cent. of the quantity 1.71."

It may be of interest to present a sample set of observations made by Dr. Rein on the operation of one of the Scheller gaps, these observations being taken from his book, "Der radiotelegraphische Gleichstrom-Tonsender," page 38.

The capacity in the primary impulse circuit was C_1 = 0.111 λf., inductance in the same circuit = L_1 = 1.915 μh., resistance in that circuit = W_1' = 0.45 ohm, primary wave length = λ_1 = 866 meters, supply voltage = 435 volts.

In the following table W_g is the resistance in the supply circuit in ohms, L_g the inductance of the supply circuit choke coil in henrys, A the energy supplied by the generator in watts, $i_g^2 W_g$ the energy loss in the supply circuit resistance, A_H the energy in the primary impulse circuit, A_{II} the equivalent energy in the antenna or secondary circuit, EFF_f the efficiency of the gap discharger, EFF the over-all efficiency.

V	L_g	A	$i_g^2 W_g$	A_H	A_n	EFF_f	EFF
230	1.354	368	166	202	100	49.5	27.2
230	0.796	369	166	203	100	49.2	27.1
230	0.294	355.5	154.5	201	98.6	49.0	27.7
230	0.0693	347	147	200	94.6	47.3	27.3

EMIL J. SIMON: The only practical systems of radio communication using direct current at the present time, to my knowledge, are those of Lepel, Lorenz, and Poulsen. In 1907 or 1908, Dr. Seibt, then chief engineer of the Poulsen Company, in Germany, began to work on this type of apparatus. At that time the German Poulsen Company was affiliated with the Lorenz Company.

I cannot find that the Duddel tone circuit was used around the direct current arc or spark dischargers prior to 1909, by which time the Amalgamated Radio Company (Poulsen system) had failed and was therefore no longer associated with the Lorenz Company. After that time, therefore, the work of Dr. Seibt was independent of that of the Lorenz Company. It must be admitted that the arrangement used by Lepel in his sets is quite similar to those of the Multitone sets. The Lepel arc discharger, which consists of two plane sheets of water-cooled copper separated by a thin layer of paper which is gradually burnt up by the discharge, is known to be effective in practice; and stations of this type have been used for several years. One of them in Jamaica has been working since 1909. I believe that the Lepel discharger has a sufficiently high inherent damping to make tuning between the antenna and impulse circuits unnecessary.

In Dr. de Forest's laboratory, during the winter of 1908-1909, a number of experiments were carried on with a water-cooled copper-brass arc discharger, the arc taking place in an atmosphere of water vapor. The supply current was at a tension of 220 to 500 volts. In the spring of 1909, Duddell circuits were in use across this arc, and high notes were produced at the receiving station. Mr. Pickerell, then operator at the Waldorf, repeatedly heard these tones. In the summer of 1909, a larger discharger was built. Two wheels, 15″ and 24″ in diameter respectively rotated, and the arc took place between their nearest points and in water vapor. This 5 kilowatt transmitter enabled transmission to Philadelphia

and Albany, using a tone circuit arranged to give a note of . to 1,000 cycle pitch. The voltage, which was always less than 1,000, was obtained from two 500 volt machines in series. In all cases, tuning between the closed circuit and the antenna circuit *was* required, because the damping of the arc was not sufficient to produce aperiodicity. In the summer of 1909, the Seibt quenched spark gap was substituted for the arc. It was found that at least 500 volts was required to break down the gap and start the discharge. Only one gap could with advantage be used therefore, and the energy obtained was less than 0.5 kilowatt. At the Metropolitan Tower station, where 1,000 volts was available, two gaps were used in series. These gaps were of metal, diameter 5 to 8 cm., and separation of sparking surfaces less than 0.01″ (0.25 mm.). The gaps were water-cooled. Under these conditions, as much as 2 kilowatts output was obtained. The tone circuit was also used. It must be remembered that these arrangements were entirely experimental, because for larger energies, higher supply voltages than 1,000 were necessary, and such voltages were not at our disposal. Furthermore the apparatus was difficult to construct satisfactorily and not easy to operate. This work was therefore discontinued.

As regards Figure 17 of Dr. Rein's paper, I cannot believe that the arrangement is operative if circuits II and III are not syntonised. The quenched gaps used in 1909 under similar conditions always required such tuning. I should be interested to know to what extent the arrangement of Figure 17 has ever been used commercially.

ALFRED N. GOLDSMITH: Speaking on behalf of Dr. Rein, I may state that the patents of Lepel and Scheller in Germany are numbered 232,174 and 237,714 respectively, and, inasmuch as they cover gap dischargers intended to secure "ideal" impulse excitation, it is evident that the experimental work of these investigators must have been nearly contemporaneous. As regards the tuning of circuits II and III the highest efficiency (as measured by ratio of antenna power to power supplied by the direct current generator) is undoubtedly obtained when circuits II and III are tuned, yet even when they are not tuned there is considerable transfer of energy and the tone remains *pure*. This shows that the damp-

ing of the gap discharger is sufficient to secure perfect quenching without the influence of the reaction of the antenna circuit on the impulse circuit.

It has been mentioned in the paper that instead of using direct current to supply the gap, for higher powers particularly, low frequency alternating current (say at 15 cycles) may be advantageously used because of the ease of raising it to the high voltage necessary when several gaps are placed in series.

It has been questioned whether a pure tone can be obtained under such circumstances. If the wave form of the alternating current supplied is very flat-topped, the effect will be practically identical with that secured with direct current. Such flat top waves can be secured either by appropriate design of the alternator or by the use of a transformer, the iron of which is being worked near saturation. But even if a sinusoidal alternating current supply is used, the note obtained will be the result of superposing say a 15 cycle note and a 500 cycle note; that is, a throbbing or pulsing note which is in no wise objectionable or less easy to read than the pure and smooth tone.

ROBERT H. MARRIOTT: There can be no question as to the usefulness of these sets on low powers. Whether, in view of their lower efficiency, they can compete with the quenched spark gap sets is a matter for further consideration. The obtaining of a 500-volt direct current, and the danger of working with it, must be considered. It is interesting to note that in the case of "ideal" impulse excitation, where the primary and secondary circuits need not be sytonised, various patents covering such tuning are avoided. I am sure that we feel very grateful to Dr. Rein and the Lorenz Company for this paper, which has been highly interesting and instructive.

EMIL J. SIMON: In my opinion, sets supplied with low tension direct current are most useful in low powers. This is not necessarily the case for high tension direct current. Some time ago, the idea occurred to me that a special form of storage battery might be used to supply high tension direct current. Such a battery could be arranged in a number of sections to be charged in parallel and dischargers in series. A set of this type would meet the law governing ship instal-

lations inasmuch as it operates independently of the ship's source of power.

Objections may be raised to the high cost of such a battery, which for a moderate sized set may reach say $1,500. Against this must be set the saving resulting from the elimination of the motor-generator, transformer, and high tension condensers. The efficiency of such storage battery would probably be higher than that of a motor-generator set, and therefore the capacity of the battery need not be as large as might be expected from the power required to run the motor-generator. That this is the case is easily seen when it is considered that motor-generator efficiency may well be 50% and transformer efficiency 80%.

ROBERT H. MARRIOTT: Relative to Mr. Simon's proposal to use high tension storage batteries, I am convinced that the cost of such batteries would be excessive, and that their maintenance would be a very serious item.

EMIL J. SIMON: Such batteries can readily be secured with a two years' guarantee. Actual quotations on such batteries show the cost to be not excessive compared with that of the usual quenched spark equipment.

ROY A. WEAGANT: The Multitone system has one very interesting aspect, namely, the production of a uni-frequent radiation without the necessity of sharp tuning of antenna and impulse circuits. The variability of tone using a generator of commercial frequency is also of importance. These advantages are probably offset by the greater number of pieces of accessory apparatus, and the probably lower efficiency. So that the commercial advantages of the system are not sufficient to render it advisable to displace quenched spark apparatus in its favor.

As regards the damping which a properly constructed gap may introduce in a circuit, it is to be noted that under certain conditions an ordinary quenched spark gap will permit detuning without loss of energy in the secondary circuit. Of course, the range thru which this effect is present is limited. The more plates there are placed in series for a given voltage, the greater the degree of detuning permissible.

However, such gaps are not practicable because of the danger of short circuiting of sections in which the separation is so small.

ROBERT H. MARRIOTT: The Multitone system has certainly one marked advantage, namely that dots and dashes can be sent on different notes, and that a certain degree of secrecy and selectivity can be thus secured.

ALFRED N. GOLDSMITH: The use of a two note system of transmission, one note representing dots and the other dashes was proposed and operated by a Pennsylvanian inventor, Murgas, as early as 1905. It is not generally known that messages of this sort were sent between Scranton and Wilkesbarre at the end of 1905. Indeed, it is rather surprising that the system, which seems to have been considerably in advance of its time in a number of respects, should have fallen into oblivion. Among the advantages claimed for it were secrecy and speed, the latter in view of the elimination of all dashes.

H. E. HALLBORG: In the Clifden station of the Marconi Company, we have an instance of the use of a high tension storage battery acting as a direct current supply source for gap dischargers. In this station there are 8,000 cells in series, connected by an elaborate series of disconnecting switches. They are charged by four 5,000 volt generators in series, and the batteries are kept floating on the line. It is found that there is too much commutator sparking in the generators if the storage batteries are not used.

It is also found that, by a proper adjustment of the disc discharger, a single wave is radiated. The tone is determined by the rate of rotation of the disc. One of the most ingenious parts of the entire equipment is the automatic battery disconnector.

I find one very interesting point in Dr. Rein's paper, and that is the continual trend away from direct current and toward alternating current. In spite of the original design of the set, alternating current creeps in, and finally alternaters are used. The reason for this is not far to seek when one considers the problems of energy storage at low potentials and the almost insuperable difficulties in the way of generating and controlling high tension direct current.

As an example of the effect or the generator wave form on the spark tone, I recall some of my first experiments with quenched spark circuits. Dr. Rein found that a flat-topped generator wave form best suited his particular circuit conditions. However, I found that for the conditions which I desired, a sinusoidal, or single peaked wave was preferable. When these experiments were made, the obtaining of a pure note was of great importance, and presented a very baffling problem. After scores of experiments and failures, I found that a pure tone corresponding to one discharge per generator alternation could be obtained if the generator gave a very peaked wave, if the audio frequency circuit was accurately tuned to the generator frequency, and if perfectly airtight gaps consisting of 18 to 20 plates separated by 3 mils or less were used. Under these conditions, the tone lacked the typical quenching twang, and was soft, even, and mellow. When all the conditions were identical, except that a flat-topped generator wave was used instead of the peaked wave, the note at once became ragged and broken by partial discharges. The over-all efficiency of the transmitter working under the conditions mentioned was a maximum, since full advantage was taken of transformer resonance, and the power factor was accordingly very nearly unity. However, the method was not practicable owing to gap troubles caused by the use of such small clearance between the sparking surfaces and the consequent difficulties in adjustment and maintenance.

Later experiments resulted in the now well known fact that a pure, twangy, quenched note is best obtained when the audio frequency circuit is about 30 to 40% detuned Under these conditions, the wave form has apparently no effect but the efficiency is far below that obtained by the method first mentioned.

JOHN L. HOGAN, Jr. (by letter): In connection with the Rein and Lepel systems, in which there is a definite wave frequency and a definite audible group frequency and often also a third pulse or excitation frequency, it is interesting to note some early work of R. A. Fessenden. By the use of cooled gas dischargers operating on high voltage direct current (which were exhaustively treated by Dr.

Austin, and are described by him in the "Bulletin" of the Bureau of Standards, May 1907, pp. 325-340) it was found possible to secure excellent efficiencies. Fessenden had two methods for securing audible variation in the wave amplitude, (1) by the static time constant of the arc charging circuit, and (2) by tuning the generator, inductance (so-called "choke coils") and condenser to the audio frequency desired. The three-frequency method of transmission is described in his U. S. patent 727,330, applied for March 21, 1903, and was intended for sets in which unvarying tone frequency was a desideratum. Various alternating current schemes have been found more useful in practice, from the viewpoints both of economy and simplicity, and therefore predominate in practice.

Some seven years ago, Dr. de Forest and I had occasion to transmit musical tones by radio, in distributing the alternating current music of the Telharmonium. The method found best involved superposing the Telharmonium currents upon a direct current source supplying a gap discharger, by connecting the terminals carrying the composite cross-currents to either end of the feed line impedance thru condenser banks of about 0.5 microfarad. Using small superposed energies it was possible to transmit music upward of thirty miles.

It is understood that the Rein-Lorenz Multitone system had had large and successful application abroad, and such records of service as may be announced from time to time will be welcome supplements to Dr. Rein's most interesting paper.

SOME RECENT RADIO SETS OF THE MARCONI WIRELESS TELEGRAPH COMPANY OF AMERICA.*

By ROY A. WEAGANT.

(Designing Engineer of the Marconi Company.)

The purpose of this paper is to describe some recent radio sets designed for the Marconi Wireless Telegraph Company of America to meet the new specifications of the United States Navy, and to consider further certain interesting points in the design and operation of such sets.

The manufacturing plant and laboratories of this company are located at Aldene, New Jersey, where a force of approximately two hundred men are engaged exclusively in the construction and testing of radio apparatus. For testing the sets under conditions of commercial operation, in addition to an artificial antenna, an outdoor aerial is provided. (Figure 1.) This aerial is supported by two 200 feet (65 meter) steel towers, 450 feet (148 meters) apart.

For the sake of clearness, we shall consider the apparatus beginning with the point of entry of the direct current power, namely the switchboard, and pass successively thru the automatic starter, the D. C. motor, the alternating current generator, the power transformer, the closed circuit of the transmitter, the open circuit of the transmitter, and the relay key and receiver.

The switchboard (shown in front view of Figure 2 and in rear view of Figure 3), consists of a slate panel approximately 6 feet by 2.5 feet, and carries the following instruments: D. C. voltmeter, D. C. ammeter, A. C. voltmeter, A. C. ammeter, A. C. wattmeter, frequency meter, motor field rheostat, generator field rheostat, main A. C. switch, main D. C. switch, D. C. circuit breaker, solenoid switch for opening the A. C. field circuit and one side of the A. C. armature circuit, (this solenoid switch is ordinarily remotely controlled by the aerial switch, but may be controlled by) a double pole

* Lecture delivered on October 1st, 1913.

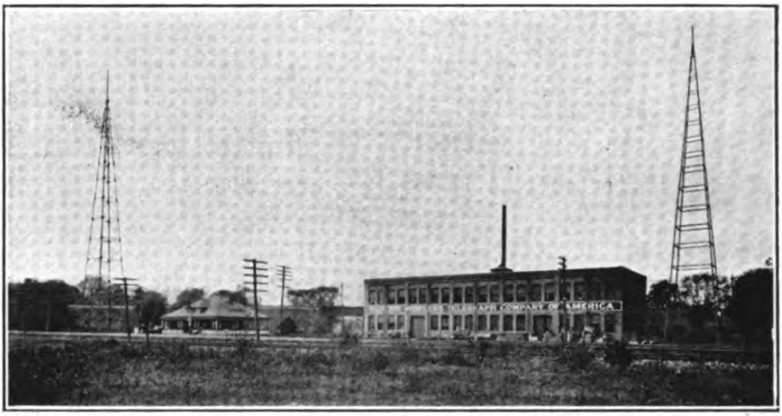


Figure 1

Figure 2

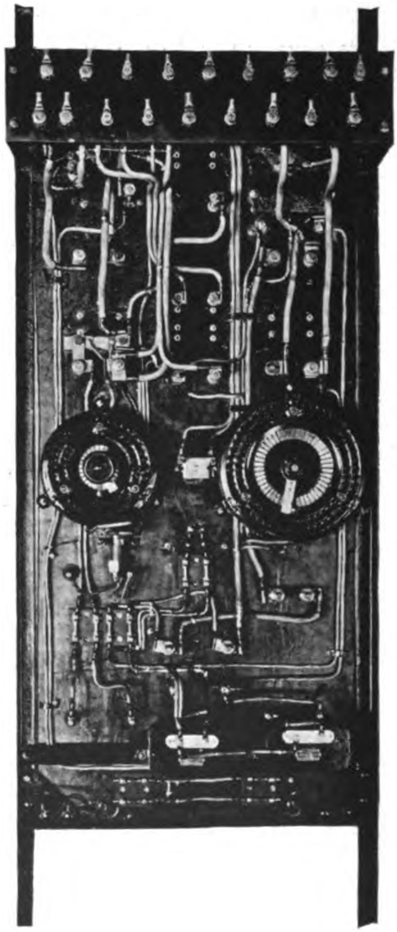


Figure 3

switch on the panel board; a push button for controlling the automatic starter, and a spare switch.

Figure 4 shows the marine type of automatic starter supplied by the Cutler-Hammer Company, which is mounted on a slate panel, together with seven-pole double-throw switch the purpose of which is to connect the automatic starter to either of two motor generators. The entire assembly is enclosed in a metal case.

The motor generator provided with these sets, the armatures of which are shown in Figure 5, is supplied by the Crocker-Wheeler Company. The machine is of the two-bearing type, semi-enclosed. It consists of a two pole, 120 volt, 2000 R. P. M., D. C. shunt wound motor and a 220 volt, 500 cycle, single-phase generator. The generator is of the rotating armature type, the complete rotor being shown in Figure 6. This generator has special electrical characteristics which particularly fit it for use with quenched spark sets.

The protective devices employed consist essentially of condensers, spark gaps, and resistance rods connected between each side of the line and ground. Fuses capable of carrying the total current of the circuit to which the device is connected are provided, and so arranged that the short circuiting of any of the protective condensers or spark gaps blows the corresponding fuse. It is thus impossible to operate the set with a defective protective device in any of its circuits. The various units composing the device are mounted on a slab of insulating material, and enclosed in a cast iron case. An appropriate value of the condenser used has been found to be 0.05 μf. and this condenser must be capable of withstanding 1,000 volts continuously applied. The resistance rods have approximately 25,000 ohms resistance. The points at which these devices are inserted are as follows: motor armature and field circuits, generator armature and field circuits, primary of power transformer, blower and rotary gap motors, (one protective device common to both field and armature).

The operator's key controls the relay key, which is illustrated in Figure 7. In addition to breaking the main A. C. circuit, the relay key operates contacts whereby the ground circuit of the antenna is opened, the detector is short-circuited, and the telephone circuit is opened. The arrangement adopted makes it possible to receive between dots and

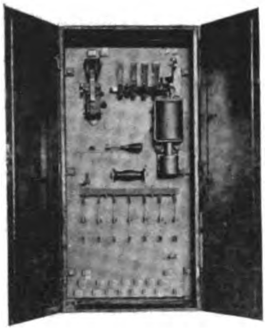


Figure 4

Figure 7

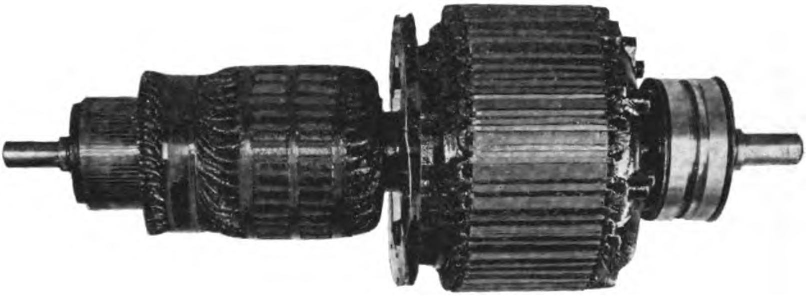


Figure 5

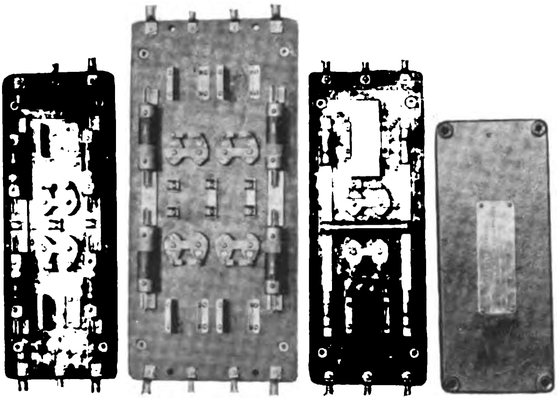


Figure 6

dashes, while transmitting. Figure 8 shows the relay key reactance, which can be adjusted to six different values by means of the switches mounted on its top. This reactance is used to reduce arcing at the main A. C. contacts of the relay.

Photographs of the exterior and interior of the transformer are given in Figures 9 and 10. The transformer is open core, air cooled. It is approximately 10 inches in diameter and 30 inches long (for the two or five K. W. sizes). The primary is wound with a number of insulated conductors in parallel, whereby eddy current losses in these conductors are considerably reduced. The core is of laminated silicon steel. A micarta tube is employed as a separator between the primary winding and the secondary sections. A perforated cover encloses and protects the secondary, while permitting a free circulation of air for cooling purposes. Two insulators on the top of the case carry the secondary terminals, and a third insulator carries a metallic ball connected to ground. The metal terminals at the tops of these insulators act as protective spark gaps and limit the potential strains between the secondary terminals or between the secondary winding and ground. The danger of puncturing the insulation between the primary and secondary windings thru resonance phenomena (and consequent enormous rises of potential) in the transformer secondary capacity circuit, when the connections to the spark gap are accidently opened, is thus obviated by the connection to ground on the third protective gap terminal.

The transmitter construction will next be considered in detail. The complete 5 K. W. transmitter is shown in front, side, and rear views in Figures 11, 12, and 13. The transmitter consists of a number of parts conveniently and compactly arranged, and supported on a slate panel. The units are as follows: a quenched spark gap with blower (A), leyden jar condenser and rack (B), an oscillation transformer (inductive coupler) (C), the aerial inductance (D), a switch for changing wave lengths (E), and an aerial ammeter (F).

The transmitter here shown is designed so that eight definite and predetermined wave lengths lying between 600 and 2,000 meters may be instantly obtained by the setting of a single rotary switch, E, which makes connections in both

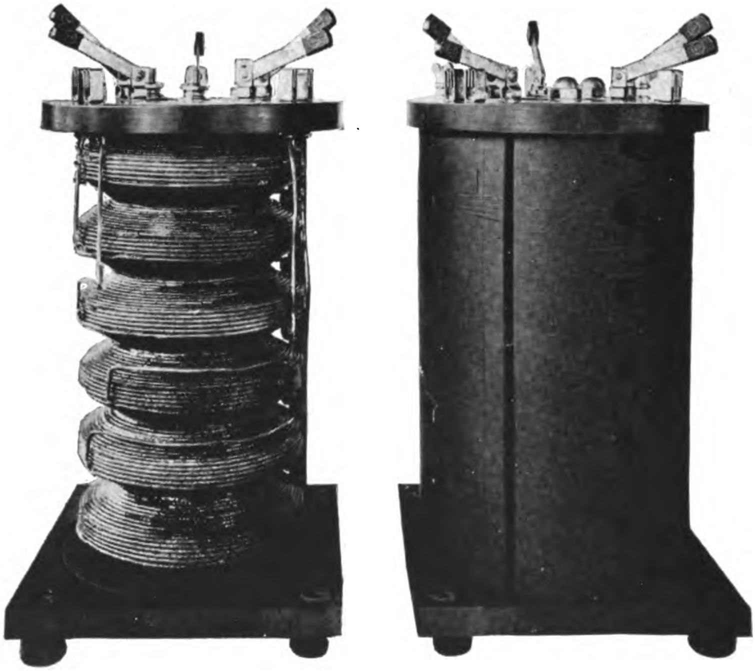


Figure 8

Figure 9

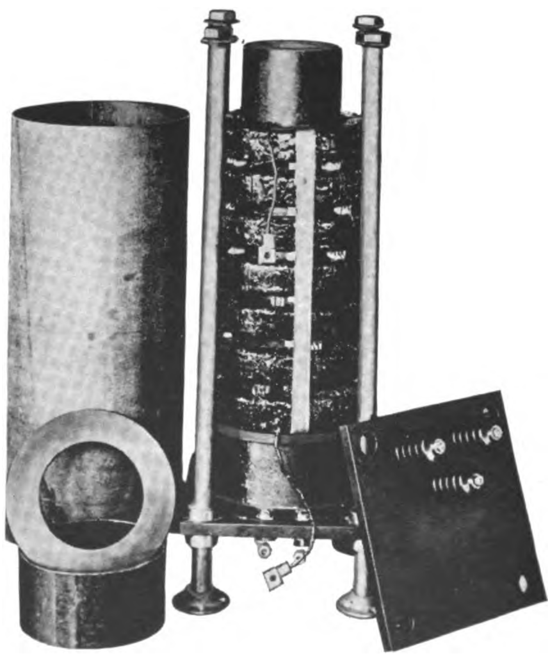


Figure 10

open and closed circuits. A preliminary adjustment to suit the particular antenna used is necessary. The connections, (which are particularly well shown in Figures 12 and 13) from the switch in the aerial circuit to the aerial inductance are made thru very heavily insulated flexible cables. The calibration of the primary circuit is accomplished at the factory. The fixed wave lengths used in these sets are 625, 750, 875, 1,000, 1,300, 1,575, 1,800, and 2,000 meters.

It is also possible to obtain any intermediate wave length between the designated limits by setting the fixed wave length switch to the wave length lying immediately below that desired, and rotating the handle of the inductive coupler C until the primary circuit shows the desired wave length as indicated on a wave meter. The antenna is then tuned by rotating the handle of the aerial inductance D until the aerial ammeter F gives the maximum indication. During this process, the coupling between the primary and the antenna circuits must be varied, which can be readily accomplished by pushing the handle of the oscillation transformer C in or out. It will be seen by reference to the illustrations that the wave length changing switch E consists of two blades mounted on a micarta tube at a separation of about 24 inches (60 cm.), these blades being arranged to rotate with the switch handle. Supporting the jaws of the switch, which are connected to the appropriate taps on the inductances, are two micarta plates thru which the micarta tube supporting the blades passes. The support of the primary switch is the one nearer the panel, and the support of the secondary switch is at the extreme rear of the unit.

The oscillation transformer consists of two spirals, the primary one being fixed, and the secondary being movable in such a way as always to remain parallel to the primary. These coils, which are shown in Figure 14, consist of copper ribbon wound in a spiral groove cut in an insulating plate support. The plate supports are placed facing each other. Eight taps are taken from the primary to the wave length switch, and a sliding contact is arranged so that rotation of the handle of the oscillation transformer produces a continuous variation of inductance sufficient to cover the range between any two fixed wave lengths.

Attached to the secondary are three flexible leads. The

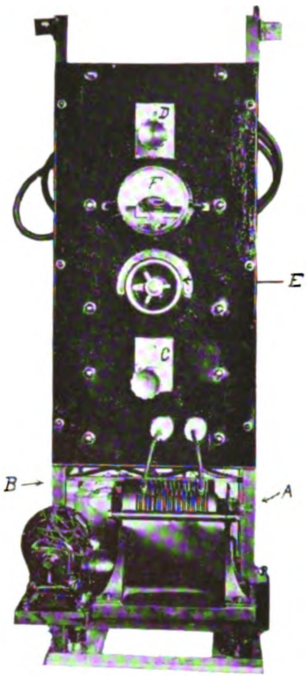


Figure 11

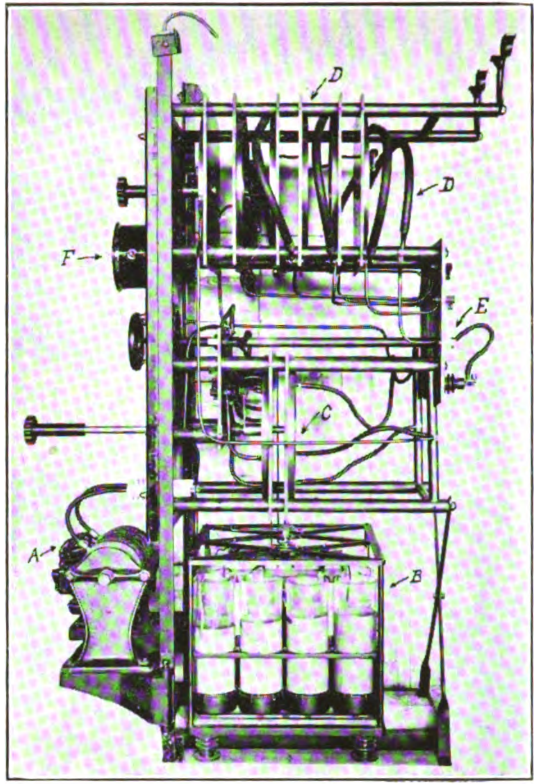


Figure 12

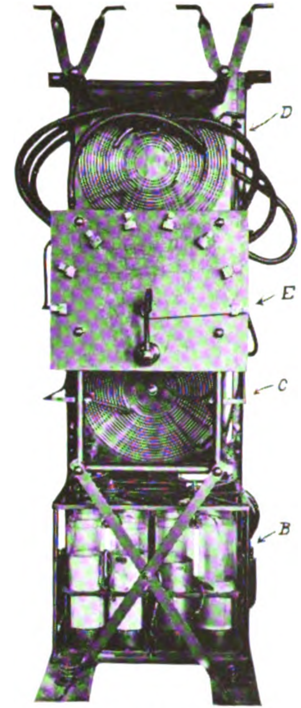


Figure 13

first of these is connected to the continuously variable portion of the antenna tuning inductance and thence to the ground. The second tap is connected to the first jaw of the wave length switch. The third tap is connected to the end of the antenna tuning inductance which is variable in steps. It will thus be seen that the aerial tuning inductance consists of two portions; a continuously variable portion which is nearer the ground than the secondary of the inductive coupler, and a portion which is variable in steps consisting of a number of coils placed nearer the antenna than the secondary of the inductive coupler. The basis of this arrangement is the necessity of using less than the entire secondary coil of the inductive coupler for tuning the antenna at short wave lengths and the further necessity of using the entire secondary coil of the coupler to obtain sufficient coupling at longer wave lengths. The advantage of placing the continuously variable portion of the antenna tuning inductance in the ground side of the inductive coupler is that it is then in circuit regardless of the position of the wave length switch. The portion of the aerial tuning inductance which is variable in steps consists of five spirals identical in construction with those of the inductive coupler. From these, seven are brought to the remaining jaws on the secondary portion of the wave length switch.

The primary condenser consists of sixteen Leyden jars, each having a capacity of 0.002 μf. The entire number is connected in parallel. The jars are of the usual silver and copper plated type. Each group of eight jars is mounted on a tray which can be slid out of the rack thru the front of the panel without disturbing any connections. This is accomplished after rotating the spark gap at the front of the panel on either of its hinges so that it will no longer obstruct the passage of the tray. Broken or defective jars are thus easily replaced. The rack and the sliding trays are shown in Figures 16 and 17.

The construction of the spark gap is clearly visible in Figure 18. It consists of fifteen plates with fourteen insulating gaskets between them. These plates and gaskets rest on a tube of insulating material, and lateral displacement is prevented by two more tubes at the sides. Thru these tubes run steel tie rods which hold the two vertical end castings

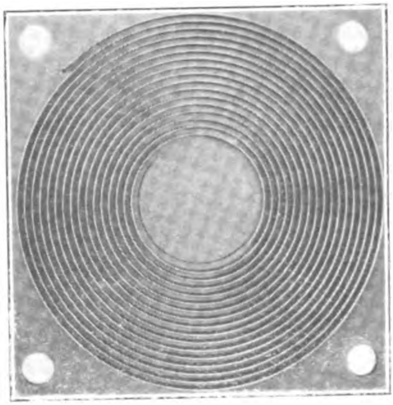


Figure 14

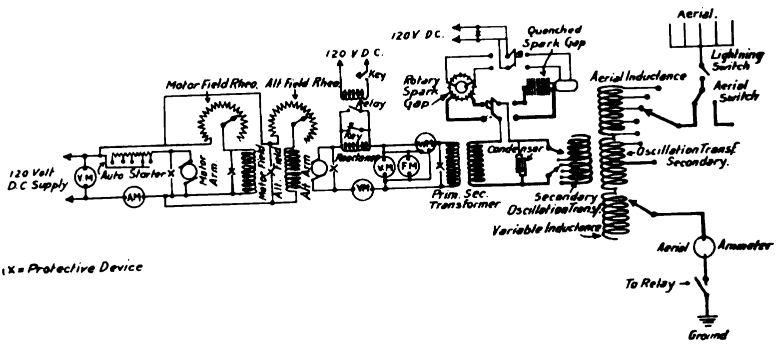


Figure 15

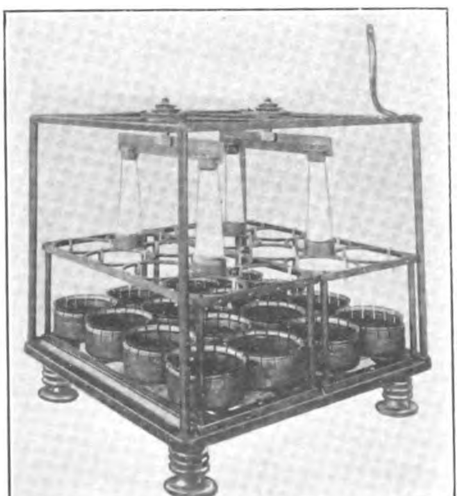


Figure 16

rigidly in place. A set screw at one end permits clamping the plates and gaskets very tightly against each other. Between the two end plates of the gap and the end castings are heavy discs of insulating material. The gap plates consist of copper castings, the sparking surfaces being inserts of electrolytic copper soldered and spun in place, and ground dead true, and parallel to the gasket bearing surface. The sparking surfaces are raised above the gasket bearing surfaces to such an extent that the separation of the sparking surfaces when the gap is assembled is approximately one-third the thickness of the gasket itself. The material used for the gaskets is press-board especially treated so that an air-tight joint between the plates is secured.

Attached to the gap is a motor-driven blower which forces air up between the flanges of the plates and prevents overheating. The construction of the side of the gap is such that the cooling air must pass between the flanges before escaping. The rotation of the gap and blower motor about either of two hinges is necessitated by the limited space available in many ship installations and the difficulty of reaching the back of the panel from either side.

In these sets an auxiliary rotary spark gap of the non-synchronous type is provided. It is intended for special naval service in times of war. A considerably larger number of studs than usual were required because of the comparatively high frequency of the alternating current supply.

A six-pole double-throw-switch provides means for shifting from the manually operated antenna switch to the relay key.

The receiver, the wiring diagram of which is given in Figure 20, is of the two-circuit, inductively coupled type. It contains the following parts: primary of the inductive coupler (A), secondary of the inductive coupler (B), antenna tuning inductance in the primary circuit (C), primary variable air condenser (D), secondary variable air condenser (E), potentiometer (F), carborundum detector (G), cerusite detector (H), test buzzer (I), coupling controller (J), detector protective condenser (K), detector stopping condenser (L), coupler primary switch (M), (dividing the transformer primary into steps of ten turns), coupler primary switch (N), (for variation by single turns), aerial tuning inductance switch (O),

Figure 17

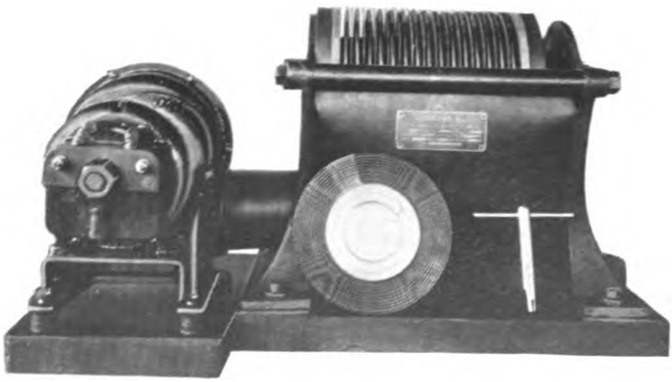


Figure 18

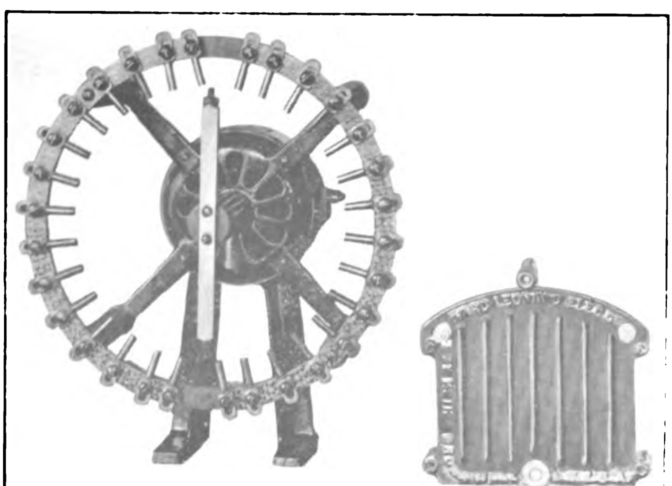


Figure 19

transformer secondary switch (P), test buzzer switch (Q), primary condenser switch for connecting condenser in series to, or in parallel with the total primary inductance or for disconnecting it entirely (R).

The inductive coupler consists of a fixed primary, and a movable secondary mounted on a rod and controlled in its motion by a flexible metal band passing over a number of pulleys. The coupling is thus varied thru a wide range by a single rotary motion of a knob. Both primary and secondary coils are divided into four sections connected to the controlling switches in such a way that dead ends are avoided. Sufficient inductance is provided in both circuits to work up to wave lengths of 7,000 meters in the case of the "long range" tuner, and up to 4,000 meters in the case of the "short range" tuner. Compactness of the coils (in combination with the unusual range of wave lengths) demands special coil construction in order that high efficiency may be obtained. The variable air condensers are of the conventional type, counterbalanced so as to rest in equilibrium in any position. The potentiometer, which provides for fine adjustment of the voltage across the detector, is of a rotary type.

Two detectors, of different operating characteristics, are provided. The carborundum detector is of moderate sensitiveness and great stability. The cerusite detector is of extreme sensitiveness. A switch is provided for using either of these at will. Separate binding posts are provided in order that any other detector can be connected in place of those furnished.

During transmission, a large condenser (K) is connected across the detector to protect it against being thrown out of adjustment.

The entire receiving apparatus is so mounted that the exterior case can be removed without interfering in any way with the connections, all parts being mounted on the heavy front panel which is supported by right angle brackets attached to the base.

The Marconi wavemeter, from the designs of Mr. Harry Shoemaker, is shown in Figures 24 thru 28. Figure 24 shows the instrument in its case. Figure 25 shows the various elements of the instrument, A, B, C, and D being the coils used to cover the various ranges of wave lengths. E is the con-

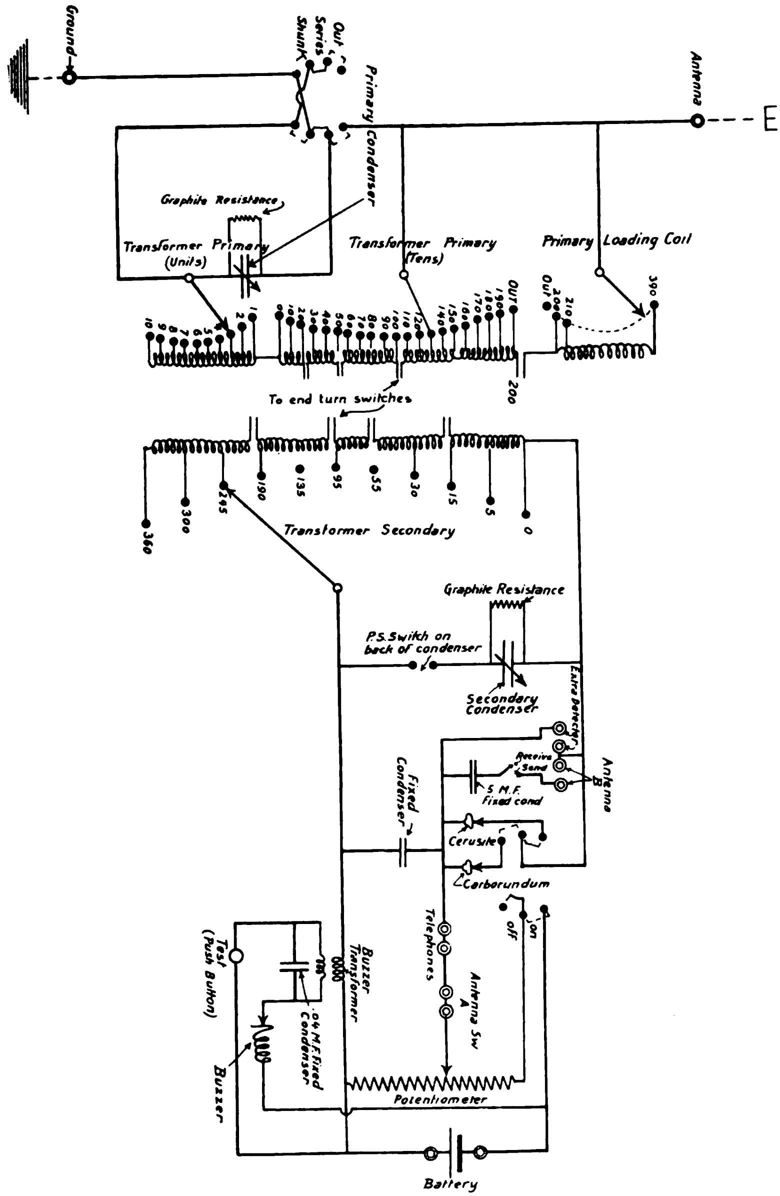

Ground
Out
Series
Shunt
Primary Condenser
Antenna
E
Graphite Resistance
Transformer Primary (Units)
Transformer Primary (Tens)
Primary Loading Coil
To end turn switches
Transformer Secondary
Graphite Resistance
P.S. Switch on back of condenser
Secondary Condenser
Extra Detector
Receive
Send
S.M.F. Fixed cond
Antenna B
Fixed Condenser
Cerusite
Carborundum
Telephones
off
on
Antenna Sw A
Test (Push Button)
Buzzer Transformer
.04 M.F. Fixed Condenser
Buzzer
Potentiometer
Battery

Figure 20

denser case, with attached brackets for holding the inductances F and G. The buzzer, H, the detector, I, and the thermo element, K, (of Figure 26) are also mounted on this case. The variable air condenser is shown in Figure 27, while Figure 28 shows the complete instrument with the galvanometer, L, and the "pick-up" coils, L and M.

This instrument covers a range of wave lengths from 100 to 5,000 meters, and is arranged for measurements of inductance, capacity, and decrement as well as for wave length. A plug containing a known resistance may be inserted in the oscillatory circuit, and the decrement of the instrument itself at any wave length determined. In addition, coils are provided for measuring the wave length of incoming signals, in which case the instrument is employed in much the same way as an ordinary receiver.

We shall now discuss briefly certain matters of design and construction. The alternating current instruments on the power switch boards must be so constructed as to read correctly on wave forms differing widely from the pure sinusoidal type. The alternating current circuits need not be provided with any special protective devices against excess current inasmuch as the characteristic of the generator are such that it is not possible to draw more than the load current. Nevertheless these circuits have been provided with fuses. Fuses are used because it has been found impossible to construct suitable 500 cycle circuit breakers.

The motor of the motor generator set must be provided with closer speed regulation than is common with the usual commercial set, namely from 3 to 5%. The generator is purposely designed to have very poor regulation, so that the voltage drops markedly as the load is applied.

A complete theory of the action of the transformer, with particular consideration to the transient phenomena involved, is beyond the scope of this paper, but will be considered in a later communication. Certain general points in the design are of interest, and will be discussed. In order that the transformer operate properly in connection with a quenched spark transmitter, it is essential that its characteristics shall bear certain relations to the other circuit constants. Figure 23 shows a resonance curve obtained by varying the capacity connected to the secondary, and observing the current in the pri-

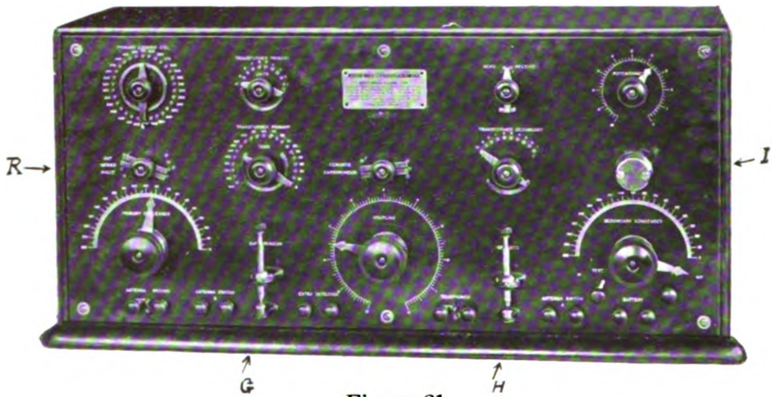


Figure 21

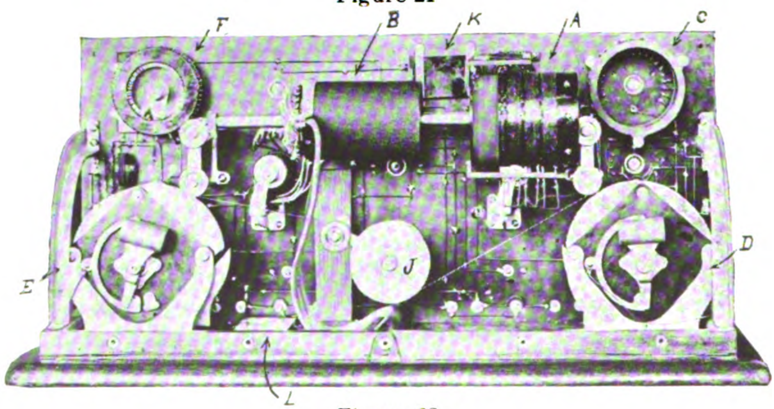


Figure 22

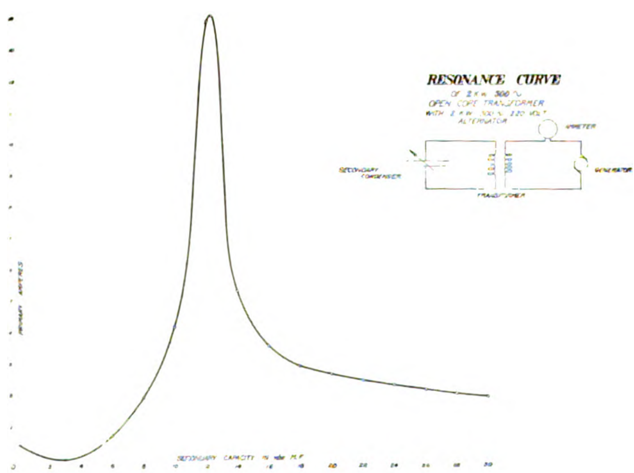


Figure 23

mary circuit. It will be noted that the point of maximum primary current, or "resonance point," is at 0.012 microfarad capacity, while, as previously stated, the capacity used in actual working is 0.016 microfarad. In other words, the natural period of the transformer circuit as a whole, is considerably greater than that of the applied E. M. F. This condition is necessary in order to secure a clear, musical note without critical adjustment. The more nearly the working point approximates to the resonance point, the higher the power factor of the circuit, but the more difficult becomes the adjustment for a clear note. Under the working conditions specified, the average power factor is about 80%.

Completely to predetermine mathematically the constants of the transformer is not possible at present, but certain quantities may be easily obtained by the following methods. In designing the primary and core, it is usual to start by assuming some length for the core which has been found appropriate in practice. The flux density chosen generally lies between 6,000 and 15,000 lines per square inch (1,000 to 2,500 lines per sq. cm.). The cross section is usually determined by experience. The following empirical formula connects the number of primary turns with the flux produced in a straight open core, of given dimensions. In this formula ϕ is the total flux produced per ampere-turn in the circular core, L is the length of the core in inches, D the diameter in inches:

$$\Phi = \left(10 + \frac{L}{4D}\right) D$$

Experience has shown that the magnetizing current for best operation should be about one-third of full load current. Having chosen, then, the flux density and the magnetizing current, the number of primary turns is at once obtained. The copper cross-section of the secondary wire is next determined by an approximate knowledge of the current it must carry. A number of secondary sections are then constructed, and by trial, the proper number to be used is found. This method is obviously one of cut-and-try, but we are forced to adopt it because the previous mathematical treatments of the transformer take no account of the periodically recurring transient conditions introduced by the employment of a quenched spark transmitter, and these earlier theories also assume that the transformer is operated at the resonance point. The complete

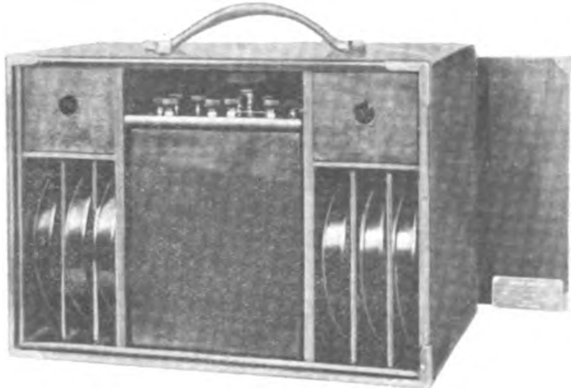


Figure 24

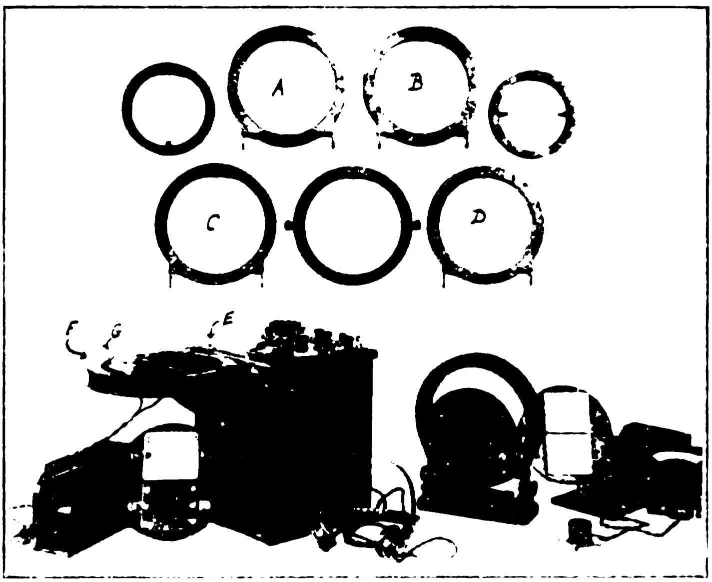


Figure 25

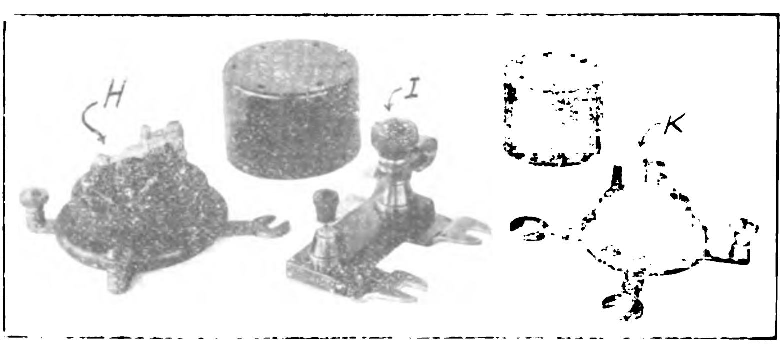


Figure 26

predetermination of secondary voltage and current must therefore await the publication of the full theory. Experience shows that the secondary open circuit voltage is between 0.4 and 0.7 of the condenser or spark gap voltage. It will be found that the product of the secondary open circuit voltage, the secondary current and the power factor is approximately equal to the power input. Since all these quantities except the secondary current may be regarded as known, it is possible to calculate the latter. The last-mentioned relation was first pointed out to me by Mr. Guy Hill, of the United States Naval Radio Service.

The quenched gap exerts a frequently neglected influence on the coupling required for satisfactory operation of the transmitter. The greater the number of sections, and the shorter each section, the closer the coupling which must be used. It is possible therefore to work within a desired range of coupling by properly choosing the number of gap sections.

In the type of receiving set previously described, it has been necessary to cover in one apparatus an extreme range of wave lengths. However, experience shows that such receivers are preferably subdivided into those intended for wave lengths below 1,500 meters, and those designed for wave lengths greater than 1,500 meters. Radically different types of construction are required in the two cases to obtain maximum efficiency. It may also be noted that the efficiency of the modern receiver is far less than that of the transmitter, and that there is room for much improvement in this regard. It appears further, as the result of considerable experiment, that with a given aerial, the receiver must be specially designed for it if maximum efficiency is to be obtained.

The foregoing general remarks concerning quenched spark transmitter design are to be taken as merely indicative of the directions in which future research may be profitably carried on, rather than any complete solution of the problems involved.

DISCUSSION.

ROBERT H. MARRIOTT: On behalf of the INSTITUTE, I wish to thank Mr. Weagant for the interesting and valuable paper he has given us. In reference to the mineral

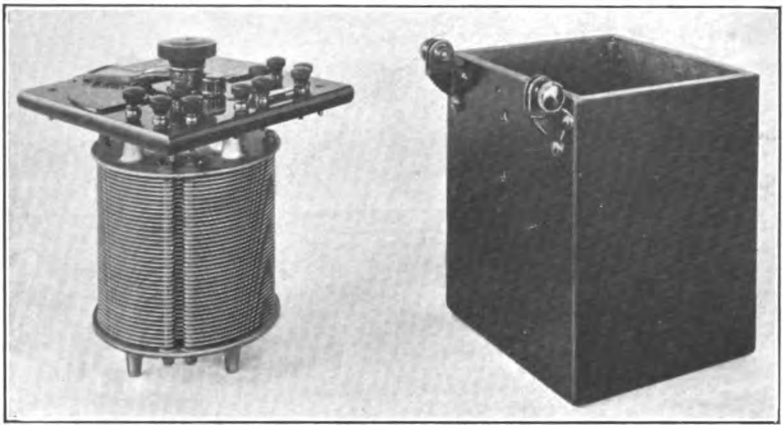


Figure 27

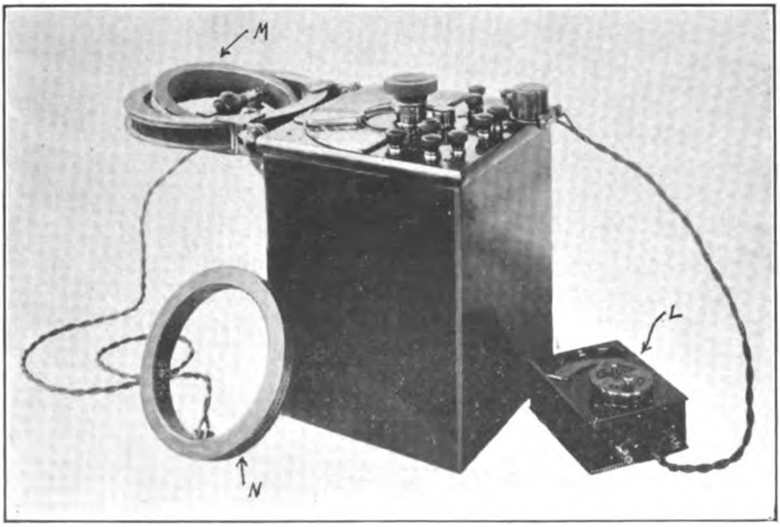


Figure 28

cerusite, which is used in the Marconi detectors, it will be found that the cerusite which is purchasable in the open market is useless for radio work. The deposit of sensitive material is located at a point known only to a Mr. Lyons, who first offered me the American rights to the use of the material. This special deposit of the material is the source of the cerusite now used by the Marconi Company.

EMIL J. SIMON: The INSTITUTE owes Mr. Weagant its thanks for the open and modest way in which he has described his work. The statement that the design of the so-called "resonance transformer" is largely "cut and try" is unfortunately true. I can, however, add to Mr. Weagant's methods a description of a method whereby the secondary of this transformer can also be almost entirely calculated in advance. In the diagram (Figure 29) L_g is the inductance of the generator, L_r that of a supplementary reactance, and L_p that of the primary of the transformer. The inductance of the secondary of the transformer is L_s, its mutual inductance to the primary M, and the transformer capacity load C_2. We use N_g for the frequency of the generator (usually 500 cycles), and N_e for the frequency of the entire circuit shown. The old "secret" which Mr. Weagant has mentioned, namely, that "resonance transformers" are not worked at resonance in cases where a clear note is desired, can then be utilized to advantage. In the case shown by Mr. Weagant, the resonance capacity load for a certain transformer was 0.012 μf., whereas the working capacity was 0.016. That is, the transformer was being used at a frequency about 16% below resonance. In my own work, I usually use between 20 and 25%. If we take 20% as an average value for the percentage difference between the resonance frequency and the working frequency, N_e becomes 400 cycles. In my design, I start by assuming a value for L_p, which has been found appropriate in practice, and then I measure L_g The quantities L_p and L_g must be added geometrically, because the currents in them are not necessarily in the same place. The capacity load, C_2, is probably known from considerations of the desired voltage, frequency, and power. The coupling coefficient for the transformer system is found from the equation

$$k^2 = \frac{M^2}{L_1 \ L_2}$$

where L_1 is the geometrical sum of L_p, L_g, and L_r. The practical problem which confronts us in this design is to obtain a clear pure note, with a given rate of quenching, and with freedom from critical adjustment. In calculating L_2, I use a formula first given by Seibt in the Elektrotechnische Zeitschrift in 1904 in an article on the theory of the resonance transformer, namely,

$$\frac{1}{N_c} = T_c = 2\Pi \sqrt{C_2 L_2 (1-k^2)}$$

For an open core transformer, and remembering that we are considering the entire circuit coupling, k may be taken as about 0.8.

ROY A. WEAGANT: I must take complete exception to the expression for T_c given by Mr. Simon. Seibt deduced this equation for a permanent condition; that is, the secondary of the transformer was not connected to any element of rapidly varying resistance such as a spark gap. Operation at the resonant point is also assumed. In our design, it is necessary to provide for the transient conditions.

EMIL J. SIMON: I wish to add that, if k is taken to mean the coupling coefficient between the primary and secondary of the open core transformer, it is given by the expression

$$k^2 = \frac{M^2}{L_p L_s}$$

and that its value is usually from 0.4 to 0.5. It is quite true that, as Mr. Weagant says, we are working under transient conditions. Still, the equation given for T_c is found to hold fairly well in practice, and gives a useful first approximation.

The ratio of turns of secondary to those on primary must be obtained also. We may start by assuming that it is the same as the ratio of secondary to primary electromotive force. As a matter of fact, resonance effects make the ratio of electromotive forces considerably greater than the ratio of number of turns. We first get the (secondary voltage)-(frequency) resonance curve for a transformer of the same general type as the one under consideration, and, knowing the percentage off resonance at which the new transformer is to work, we can observe the correction which must be applied to the electromotive force ratio to obtain the ratio of number of turns.

ROY A. WEAGANT: In working with receiving sets, I have encountered repeatedly a phenomenon for which I can find no explanation. The arrangement of instruments is shown in Figure 30. A is the antenna, B a coupling coil to C. C is a portion of a buzzer exciting circuit. Z is a primary of either receiving set X or receiving set Y; the object being to compare the sensitiveness under working conditions of two receiving sets. It may be found, for example, that the signals on set X are the louder. If, now, coil C is rotated through 180°, so that end 2 is coupled to B instead of end 1, receiving set Y is now found to give stronger signals. In the numerous cases where this effect has been observed, extreme precautions were taken to keep B and C at very considerable distances from X, Y, and Z.

JOHN L. HOGAN, Jr.: The effect may in some way be due to a change in the relative values of magnetic and static coupling between B and C as the latter is rotated. Another curious effect that has been observed in the study of receiving sets is that telephone indication and galvanometer reading do not maintain their relative ratios. For example, it is possible to secure conditions where altering the coupling to the exciting circuit produces practically no change in the strength of the telephone signals, altho the galvanometer reading may change at the same time from a positive to a negative value.

EMIL J. SIMON: Mr. Weagant has mentioned that micarta is used as the support of the spiral tuning inductances. May I ask whether in the intense field of such a spiral, no heating is produced in the micarta, at the end of an eight-hour run?

ROY A WEAGANT: No greater heating was found than when a skeleton coil employing the minimum amount of insulating material was used. Even between the primary and secondary of the transmitting inductive coupler, where there is interposed a double thickness of the micarta, no heating or additional loss was found. Of course, the spiral conductors themselves become slightly warm.

EMIL J. SIMON: I mention this because, while using micarta cores for ordinary helix coils, I found that the tube heated badly, and the construction in question had to be abandoned.

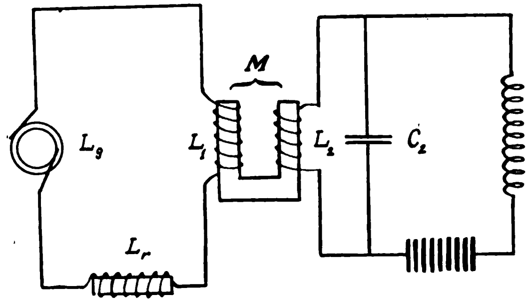


Figure 29

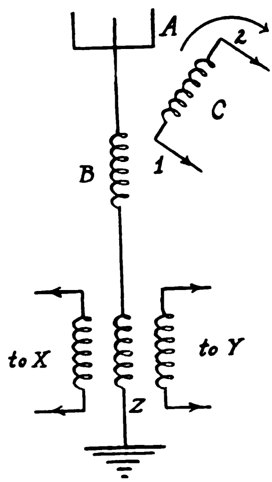


Figure 30

ROY A. WEAGANT: This might be due either to surface leakage over the micarta between uninsulated conductors, or because of actual conductivity of the micarta and consequent eddy current losses.

EMIL J. SIMON: It could not have been surface leakage because the conductors were of litzendraht, very carefully insulated with silk and a weather-proof coating. It may be actual conductivity.

FRANK HINNERS: If the losses are due to conductivity, what effect would increasing the thickness of the tube have on these losses?

ROY A. WEAGANT: It should increase the losses because the greater cross section carries with it diminished resistance and greater currents.

(Printed for Members Only.)

PRELIMINARY REPORT
OF THE
COMMITTEE ON STANDARDIZATION
OF
THE INSTITUTE OF RADIO ENGINEERS
Inc.

DEFINITIONS OF TERMS, GRAPHICAL AND LITERAL SYMBOLS.

MEMBERSHIP OF THE COMMITTEE.

ROBERT H. MARRIOTT, Chairman, United States Radio Inspector, Department of Commerce, New York, N. Y.

ALFRED N. GOLDSMITH, Ph. D., Secretary, Instructor in Radio Engineering, The College of the City of New York, New York, N. Y.

JOHN L. HOGAN, Jr., Chief of Operating and Erection Department, National Electric Signaling Company, New York, N. Y.

A. E. KENNELLY, M. A., Sc. D., Professor of Electrical Engineering, Harvard University, Cambridge, Mass.

ROY A. WEAGANT, Designing Engineer, Marconi Wireless Telegraph Co. of America, Aldene, N. J.

GREENLEAF W. PICKARD (ex-officio), Chief Engineer, Wireless Specialty Apparatus Company, Boston, Mass.

NEW YORK CITY,

September 10, 1913.

PREFACE.

The early history of new branches of engineering always shows the discouraging spectacle of a confused and ill-defined nomenclature, together with widely different connotations assigned to the literal symbols by the various investigators and authors. Such a state of affairs gives rise to untortunate misunderstandings, or, at best, to a considerable amount of unnecessary labor on the part of the practicing engineer and students of engineering.

The field of radio engineering is far from having escaped the objectionable conditions mentioned above, as is easily seen from reading either theoretical papers on the subject or the reports of the patent lawsuits.

The Committee on Standardization of THE INSTITUTE OF RADIO ENGINEERS was appointed by the Past-President of the Institute, Mr. Robert H. Marriott, and continued by President Greenleaf W. Pickard, for the express purpose of studying the terms and symbols used in the art, selecting and defining the suitable terms, and eliminating the remainder. Its further functions are to develop, and make public, standard methods of testing and rating radio apparatus, and to consider such further matters as would naturally fall within the scope of a Committee on Standardization.

As a result of more than fifty meetings and discussions, the Committee presents to the I. R. E. members and others interested the following definitions and symbols for consideration.

All those interested are requested to send to the Committee, in care of the Secretary, their comments on the following preliminary report. Coöperation of this sort will be welcomed, and will assist the committee in the early publication of a final report.

TO ALL MEMBERS:

The questions given below should be answered, and this page should be torn out and mailed to Alfred N. Goldsmith (former Secretary of Committee on Standardization), The College of the City of New York, New York City. The final action on this Committee Report will be based on the replies received.

1. With the exception of the changes suggested by you below, are you in favor of the acceptance and adoption of this Preliminary Report by the Institute?

....

....

2. If you are not in favor of its acceptance, what are your reasons for its rejection? ....

....

....

3. What criticism of the Report do you make, and what changes in the Report do you suggest?

....

....

....

(Further criticisms and suggestions may be sent on separate sheets.)

....

Signature.

....

Date.

DEFINITIONS OF TERMS.

Acoustic Resonance Device. One which utilizes in its operation mechanical or other resonance to the group frequency of the received impulses. The device most commonly used is a relay.

Air Condenser. One having air as its dielectric.

Alphabet or Code. (See "Code.")

Alternator. A rotating machine which transforms mechanical energy into electrical energy, delivering at its terminals one or more alternating E. M. F.'s. (Single phase or polyphase.)

Alternating Current. One which reverses its direction successively with time, whether periodic or non-periodic. (See also Free Alternating Current, Forced Alternating Current.)

Ammeter. A current measuring instrument indicating in amperes or fractions thereof.

Amplification. The ratio of the useful effect obtained by the employment of the amplifier to the useful effect obtained without that instrument.

Amplifier or Amplifying Relay. One which modifies the effect of a local source of energy in accordance with the variations of received signals, and in general produces a larger indication than could be had from the incoming energy alone.

Angular Velocity of a periodic alternating current in radians per second. 2π times the frequency in cycles per second.

Antenna. A system of conductors designed for radiating or absorbing the energy of electromagnetic waves.

Antenna Resistance. The ohmic resistance in the entire antenna circuit.

The energy consumed in the antenna resistance contributes nothing to the radiation, but produces only heat.

Arc or **Spark.** See "Spark."

Arc Convertor. An arc used for (a) the conversion of alternating to pulsating direct current, or (b) the conversion of direct to alternating or pulsating current.

Arc Converters of Type (b) are classified as follows:

Class (1) Those for which the amplitude of the (approximately) sinusoidal current produced is less than that of the direct current.

Class (2) Those in which the amplitude of the (approximately) sinusoidal current is at least equal to that of the direct current, but in which the direction of the current is never reversed.

Class (3) Those in which the amplitude of the initial portion of the free alternating current is greater than the direct current passing through the converter, and in which the direction of flow of the current is periodically reversed.

Atmospheric Absorption. That portion of the total loss of radiated energy due to atmospheric conductivity, reflection, and refraction.

Atmospherics (Atmospheric Disturbances in the Receiver) may be classified as follows:

(1) Electrical disturbances set up by distant discharges, and

(2) Disturbances caused by contact of charged particles with the antenna, or by the contact of uncharged particles against the antenna and their consequent electrification.

Attenuation. The progressive diminution of intensity as a disturbance advances through a transmitting medium.

Attenuation Radio. The diminution of radiant eletromagnetic energy concurrent with its passage thru a partially absorbing medium.*

Attenuation Coefficient (Radio).* The coefficient which, when multiplied by the distance of radiant transmission through a uniform medium gives the natural logarithm of the attenuation factor in that distance.

Attenuation Factor (Radio). The ratio of the radiant energy received at a distance traversed in an attenuating medium to the initial radiant energy. A numeric.

Audibility (Minimum). The condition in which there is present in the antenna the least power required for an audible

*See footnote on following page.

indication in the receiving telephones, with the particular apparatus employed.

Audibility Factor. The ratio of the telephone current producing the received signals to that producing the least audible signal at the given audio frequency. *

(An audible signal is one which just permits the differentiation of dots and dashes.) The determination of the above ratio should be made by the usual non-inductive shunt-to-telephone method, pending the adoption by the Institute of a more suitable method. The audibility factor is, in general, proportional to the square of the ratio frequency is the antenna and is often stated as the vector $(\mathbf{R_t} + \mathbf{R_s})/\mathbf{R_s}$ where Rt is the audio frequency impedance of the telephones, and R_t is the impedence of the shunt which, when connected across the telephone terminals, reduces the signal to the point at which dots and dashes can be just distinguished from each other.

Audio Frequencies. The normally audible frequencies lying between 20 and 20,000 cycles per second. (See also Radio Frequencies.)

Brush or Coronal Losses. Those due to leakage convection current through a gaseous medium.

Capacity. That property of a material system by virtue of

---

*General Considerations for Spherical Wave Distribution.

Assume that energy leaves a source. Because of geometrical considerations of the spread of energy (and depending on the nature of the waves), there will be a normal law of energy diminution with distance. At a distance *s* there will therefore be a normal energy intensity, no absorption of energy in the medium being as yet considered. Therefore (Normal Energy Intensity at Distance *s*) equals the product of (Energy Radiated) and (a Function of *s*). There may be, in addition, a dissipative absorption of energy in the medium. On the assumption that equal thicknesses of a homogeneous medium absorb equal portions of the thereupon incident energy: (Energy Intensity at a Distance *s* taking account of Distance Diminution *and* Medium Absorption) equals the product of (Normal Energy Intensity at distance s as defined above) and (ϵ^{-As}), where A is the attenuation coefficient. The actual energy intensity at distance s will, in general, be a function of (Energy Intensity at distance *s* taking account of Distance Diminution and Medium Absorption) and other physical conditions (e.g., ground losses, atmospheric reflection and refraction).

which it is capable of storing energy electrostatically.

The capacity of a system is dependent on its geometrical dimensions, its position relative to other conductors, and the dielectric constants of the surrounding media.

Capacity is measured by the ratio of the quantity of electricity stored to the potential difference at which it is stored.

A distinctive property of a capacity is that it permits the passage of electrical energy through it only in the form of displacement currents.

Capacity of An Antenna. Its electrostatic capacity measured relative to the counterpoise or ground.

Capacitive Coupler. An apparatus which electrostatically joins portions of two circuits, and thereby permits the transfer of electrical energy between these circuits thru the action of electric forces.

Capacity Reactance. A measure of that property of a circuit whereby the opposition of inductive reactance to change of an alternating current may be compensated or reversed. It is numerically equal to the reciprocal of the product of angular velocity and capacity in series with the inductance, and is always negative in sign.

Choke Coil, see Reactance Coil or Reactor.

Code (Alphabet). A system of conventional characters designed to represent letters by dots and dashes. The International Morse Code is official.

Coefficient of Coupling (Inductive). The ratio of the mutual inductance of two circuits to the square root of the product of the self-inductance of those circuits.

Coherer. A device sensitive to radio frequency energy, and characterized by (1) a normally high resistance to direct currents at low voltages, (2) a reduction in resistance on the application of an increasing electromotive force, this reduction persisting until eliminated by the application of a restoring or disturbing mechanical force, and (3) the substantial absence of thermo-electric or rectifying action.

Condenser. A material system possessing electrostatic capacity.

Conductive Coupler. An apparatus which magnetically and electrically joins two circuits having a common conductive portion (also known as a Direct Coupler).

Conductance of a conductor is numerically equal to the reciprocal of its ohmic resistance.

Conduction Current. A transfer of electrical energy guided by a conducting medium.

Convection Current. A transfer of electrical energy by separate charged particles, unguided by any material medium.

Counter Electromotive Force exists wherever there is one which opposes any electromotive force that tends to alter the flow of current in a circuit. If the counter electromotive force is due to the presence in the circuit of inductance or capacity or to thermo-electric forces, it may persist after the withdrawal of the electromotive force which was its cause; but in most other cases it persists only so long as the impressed electromotive force.

Counterpoise. A system of electrical conductors forming one plate of a condenser, the other plate of which is the ground. For alternating current, it may be used to replace a direct connection to ground.

Coupler. See Capacitive Coupler and Inductive Coupler.

Coupling. See Coefficient of Coupling (Inductive).

Critical Resistance of an oscillating circuit. Twice the square root of the ratio of the inductance of that circuit to the capacity of that circuit, both expressed in practical units. This term applies only to circuits capable of carrying free alternating currents.

Current. The time rate of transfer of electrical quantity.

Current. See also Convection Current, Conduction Current, Displacement Current, Alternating Current, R.M.S. Value.

Damping of a Circuit. The diminution of E.M. F. and current in that circuit resulting from the withdrawal of electrical energy.

Damping Factor of a simple circuit. The ratio of the effective resistance of that circuit to twice the effective inductance. (The reciprocal of a time.) This term applies only to circuits capable of carrying free alternating currents.

Decrement. See Linear and Logarithmic Decrement.

Detector. That portion of the receiving apparatus which, connected to a circuit carrying currents of radio-frequency, and in conjunction with a self-contained or separate indicator, translates the radio frequency energy into a form suitable for operation of the indicator. This translation may be effected either by the conversion of the radio frequency energy, or by means of the control of local energy by the energy received.

Dielectric. A medium that may be regarded as incapable of electric conduction, i.e., an insulator.

Dielectric Constant (or Specific Inductive Capacity) of a medium. The ratio of the capacity of a condensor having that medium as a dielectric to the capacity of a condenser having a vacuum dielectric but otherwise identical. (The dielectric constant of air is substantially unity, and therefore, for all practical purposes, air may be used in place of the vacuum in the comparison condenser.)

Dielectric Hysteresis. That lagging property of a dielectric which is measured by the energy lost when the rising and falling (displacement current)-(voltage) characteristics (dynamic) are not identical.

Dielectric Hysteretic Constant of a given dialectric. The value of the dielectric hysteresis per cycle per unit of potential gradient applied to the dielectric.

Dielectric Lag. That property of a dielectric which is evidenced by a dissimilarity, and general time lag, of the impressed (potential difference)-(time) curve as compared with resulting (displacement current)-(time) curve for a condenser having that dielectric.

Dielectric Strength. A measure of the ability of a dielectric to withstand without rupture the application of a difference of potential.

Diplex Operation involves either the simultaneous reception, or the simultaneous transmission, of two messages at one and the same station.

Discharger. An element of varying resistance in a circuit containing inductance, capacity, or both. Examples are spark gaps, commutators, arcs, etc.

Displacement Current. The electrical condition within a dielectric region of varying electric stress. It produces the same external electric and magnetic effects as the equivalent conduction current.

Duplex Operation involves simultaneously both transmission and reception at one and the same station.

Dynamic Characteristic of an Arc Converter, for a given frequency and between given extremes of impressed E.M.F. and resultant current through the arc. The relation given by the curve obtained when the impressed E.M.F. is plotted against the resultant current, both E.M.F. and current varying at the given frequency.

Dynamic Characteristic of a Dielectric for a given potential gradient applied to a given dielectric at a given frequency. The curve obtained when displacement current is plotted against the sinusoidally varying difference of potential.

Eddy Currents. Those induced in conducting masses by external varying magnetic fields, the location of these currents being primarily determined by the position of the fields and not by the configuration of the conducting mass. (That is, the conducting mass is not specially arranged to provide perfectly well-defined circuits.) Such parasitic currents are also called Foucault currents.

Effective Capacity of An Antenna. That capacity which, connected in series with an inductance of appropriate value, will give a circuit whose reactance for all practical purposes is equivalent to that of the antenna throughout the working range of frequencies. The effective capacity of an antenna is, in general, less than the electrostatic capacity of the antenna, and depends on the potential distribution along the antenna.

Effective Resistance of a Spark. The ratio of the heat produced in that spark in a complete free alternating current group to the square of the R.M.S. value of the current during that time.

Efficiency of any element of a system, or of that system. The ratio of the available and useful output to the input, both measured in the same units.

Electric Charge. Quantity of electricity, definitely situated.

Electrical Potential at any point is measured by the work done in carrying a unit charge of electricity from infinity to the point considered. (See Electromotive Force.)

Electric Stress. The cause of the electrically strained condition in the medium between two regions which are at different potentials

Electromagnetic Wave. A progressive disturbance characterized by the existence on the wave front of electric and magnetic forces acting in directions which are perpendicular to each other and to the direction of propagation of the wave.

Electromotive Force. The force which tends to displace electricity, and is proportional to the difference of potential between the two points considered.

Forced Alternating Current. One produced in any circuit by the application of an alternating electromotive force. See also Free Alternating Current.

Form Factor of an open oscillator. The ratio of the average value of the R.M.S. currents measured at all points along that oscillator to the greatest of these R. M. S. currents. For a given R.M.S. current at a current antinode in the oscillator, the field intensity at distant points is proportional to the form factor.

Free Alternating Current. That produced by an isolated electrical displacement in a circuit having capacity, inductance, and *less* than the critical resistance. See also Forced Alternating Current.

Frequency. See Audio Frequency and Radio Frequency.

Frequency Meter. An instrument which indicates the audio frequency of a source of electrical power.

Gas Rectifier. A body of ionised gas having unilateral conductivity, together with means for utilizing this property.

Group Frequency. The number of distinguishable alternating current groups occurring per second in an electrical circuit.

Note 1. The group referred to above is, in general, mainly a free alternating current which is substantially damped to extinction before the beginning of the following group or train.

Note 2. The pitch of the note in the receiving station is, in general, determined by the group frequency at the transmitting station.

Note 3. The term Group Frequency replaces the term "Spark Frequency."

Hysteresis. See Dielectric Hysteresis and Magnetic Hysteresis.

Hot Wire Ammeter. An ammeter dependent for its indications upon the changes in dimensions of an element which is changed in temperature by the passage through it of a current.

Impedance. Total opposition to current flow in a circuit in which the current is varying, and is numerically equal to the square root of the sum of the squares of the ohmic resistance and the total reactance of the circuit.

Impulse Excitation. The term applied to a method of producing free alternating currents of relatively small damping by means of the actual or equivalent removal of a source of highly damped free alternating currents from the coupled secondary circuit. As a special case, the primary current may be very highly damped, but in all cases there must be, in effect, a suppression of reaction between the circuits.

Impulse excitation is obtained in the secondary of two coupled circuits of decrements d_1 and d_2, coupling coefficient k, provided that either

(a) k^2 is small compared with $(d_1\ d_2\ /\pi^2)$, when the primary contains no spark gap, or

(b) thru the use in the primary of a spark discharger the resistance of which increases with time or diminished electromotive force, and the partial fulfillment of condition (a) above.

Note: Under the conditions of impulse excitation:

(1) The decrement of the free alternating current in the secondary circuit is appreciably that of the secondary circuit.

(2) The reaction of the secondary circuit on the primary, at least in so far as the production of the coupling frequencies is concerned, is negligible.

Inductance. That property of a material system by virtue of which it is capable of storing energy electromagnetically.

The inductance of a system is dependent upon its geometrical dimensions and the permeability of the surrounding media. In hysteresis-free circuits, inductance is measured by the ratio of the energy stored in the magnetic field surrounding a current-carrying conductor to the square of the current in that conductor, for stationary conditions. In any circuit, it may be measured by the interlinkage with the system itself of magnetic lines of force due to unit current passing through the system. An alternative method involves the measurement of the counter electromotive force at the terminals of the given conductor when the current through the conductor changes at the rate of one unit of current per second. In hysteresis-free circuits these three methods of measurement yield identical results.

Inductance. See also Mutual Inductance and Self Inductance.

Inductive Coupler. An apparatus which magnetically joins portion of two circuits.

Inductive Reactance. A measure of the opposition to an alternating current produced by the presence of inductance in a circuit, and is numerically equal to the product of the Angular Velocity and the Inductance in the circuit.

Key. A switch arranged for rapidity of manual operation.

Line of Force. A curve described in an electric or magnetic field such that the electric or magnetic force is at all points of that curve tangentially directed to it.

Linear Decrement of a circuit containing a resistance element equivalent to a spark: The difference of successive current amplitudes in the same direction divided by the larger of these amplitudes. (In circuits containing such an element, not the ratio of successive current amplitudes, but their difference is constant, and characteristic of the damping.)

Logarithmic Decrement of a circuit containing inductance, capacity, and constant resistance is one half the ratio of the electrical energy withdrawn from that circuit during a cycle to the total energy present in that circuit at the beginning of the cycle. It also equals the natural logarithm of the ratio of successive current amplitudes in the *same* direction. Note: Logarithmic decrements are standard for a complete period or *cycle.*

Magnetic Field Intensity. The flux density of magnetic lines of force produced by a magnetomotive force in air (or in a vacuum).

Magnetic Force at a point. The force acting on a unit magnetic pole placed at that point. It is numerically equal to the field intensity in a medium of unit permeability.

Magnetic Hystersis. That property of a magnetic medium which is measured by the energy losses, when the rising and falling (magnetomotive force)-(induction), i. e. (H-B), dynamic characteristics are not identical.

Magnetic Hysteretic Constant for a given material. The value of the magnetic hysteresis per cycle per unit induction for that medium.

Magnetic Induction. The magnetic flux density in a magnetic medium.

Magnetomotive Force. A force tending to produce a magnetic flux.

Microphone. An electrical contact, the resistence of which is directly and materially altered by slight mechanical disturbances.

Mutual Inductance of two circuits, each on the other, is that portion of the inductance of one due to the magnetic field common to both.

Oscillograph. A device for continuously indicating the wave form of a varying electrical quantity, e.g., voltage, current, power, etc.

Oscillating Circuit. One in which free alternating currents exist. It therefore contains less than the critical resistance.

Note: *Forced* alternating currents may be produced in circuits containing *any* combination of inductance, capacity and resistance, and resonant effects may be produced in any circuit if all three of the electrical quantities above mentioned are present.

Oscillations. See Alternating Currents, Free and Forced.

Permeability of a medium. The ratio of the magnetic flux density produced in that medium by a given magnetomotive force to the magnetic flux density produced by the same magnetomotive force in vacuum (or for practical purposes, in air).

Potential. See Electric Potential.

Radiation Resistance is the difference between the apparent total antenna resistance and the sum of all resistances which give rise to measurable dissipative energy losses, at a given wave length. This quantity is to be distinguished from antenna resistance.

Radio Communication. The radio transmission of intelligible signals.

Radio Frequencies. Those above 20,000 cycles per second. See also Audio Frequencies.

It is not implied that radiation cannot be secured lower frequencies and the distinction from audio frequencies is merely one of convenence.

Radio Frequency Resistance of a conductor. The ratio of the heating in watts to the square of the R.M.S. current in the conductor.

Radiogram. A message sent by radio communication.

Radio Telegraphy and Radio Telephony. Further divisions of radio communication. It is proposed that the term "wireless" shall be entirely eliminated, as inaccurate and inappropriate.

Reactance, (Total of a Circuit) is measured by the algebraic sum of the capacity reactance and the inductive reactance. See also Capacity Reactance and Inductive Reactance.

Reactance Coil or **Reactor.** A form of stationary induction apparatus used to supply reactance or produce phase displacement. (It is essentially an inductive resistor.)

Rectifier. A device which, when supplied with alternating current deliver unidirectional current.

Relay Key. An electrically operated key or switch.

Reluctance of a magnetic path determines the magnetic flux produced by a given magnetomotive force, and is numerically equal to the ratio of the second of these quantities to the first.

Resistance. The measure of that property of a conductor by the action of which electrical energy is transformed into heat in that conductor. It is numerically equal to the ratio of the heat energy liberated per second, measured in watts, to the square of the current in the circuit, for stationary conditions; it is also equal to the ratio of the applied electromotive force to the resulting current, both being constant.

Resonance to an Alternating Current at a given frequency. That circuit condition in which the inductive reactance at that frequency is numerically equal to the capacity reactance at that frequency; that is, the apparent reactance is zero.

Resonance Curve gives the relation between circuit energy, current, or voltage at various frequencies of excitation as a function of those frequencies.

A Standard Wave Length Resonance Curve. One wherein the abscissas are ratios of specified wave lengths to the resonant wave length, and the ordinates are ratios of the energy (or square of the current) at corresponding specified wave lengths to the energy (or square of the current) at the resonant wave length. The scale of ordinates and abscissas shall be equal.

A Standard Frequency Resonance Curve. One wherein the abscissae are ratios of specified frequencies to the resonant frequency, and the ordinates are ratios of the energy (or square of the current) at corresponding specified frequencies to the energy (or square of the current) at the resonant frequency. The scales of ordinates and abscissae shall be equal.

A Standard Resonance Curve, unless otherwise specified, is assumed to be a standard wave length resonance curve.

Resonance: See Sharpness of Resonance.

R. M. S. (Root-Mean-Square) Value of a current or electromotive force: the square root of the mean value of the squares of the instantaneous values of the current or electromotive force for any given number of cycles. The R. M. S. value of an alternating current is also the value of that direct current which produces an equal heating effect when flowing for the same time.

Selecting. The process of adjusting an element driven by a plurality of simultaneous impulses, until the ratio of desired response to undesired response is a maximum.

Selectivity of a driven element is a maximum when its damping is a minimum consistent with the use of the given indicator.

Self Inductance of a circuit. That portion of the inductance which is due to the magnetic field produced by the current in that circuit. See also Inductance.

Sharpness of Resonance of a circuit of logarithmic decrement d_2 coupled to one of decrement d_1 is defined as

$$2\pi / (d_1 + d_2).$$

It is a measure of the steepness of the resonance curve obtained from the secondary circuit. It is also a measure of the amount of detuning necessary to secure a halved-squared-current value, at very loose couplings. In circuits having linear decrements, d_1 and d_2 must be taken at the average value of the logarithmic decrements.

Skin Effect of varying currents. The non-uniform current density thru the cross section of the conductor.

Space Waves. Electromagnetic waves in a homogeneous insulator. Their distinguishing characteristic is that their energy varies inversely with the square of the distance from the source for distances great in comparison with the wave length, neglecting absorption.

Spark (or Arc) A body of ionised (and therefore conducting) gas which permits and accompanies a disruptive electric discharge. There is no sharp line of demarcation between arcs and sparks. See also Effective Resistance of a Spark.

Static Characteristic of an Arc. The relation given by the curve plotted between the impressed electromotive force and the resultant current thru the arc for substantially stationary conditions.

Surface Density of Electrification at any point of a surface is the charge of electricity per unit area at that point.

Surface Waves. Electric waves which follow the surface of a conductor.

Their distinguishing characteristics are

(a) That if they radiate over a plane sheet, at considerable distances their energy varies inversely with the distance, neglecting medium absorption, and

(b) That they are subject to medium absorption, that is, dissipation of their energy thru its conversion into heat in the guiding conductor.

Sustained Radiation consists of electromagnetic waves of constant amplitude (such as are emitted from an antenna in which flows a forced alternating current).

Transformer. A stationary induction apparatus which changes electric energy in a primary coil into electric energy in a secondary coil thru the medium of magnetic energy. As applied in radio engineering, it should refer exclusively to the so-called "power transformer."

Tuning. The process of securing the maximum indication by adjusting the time period of a driven element. (In transmitter or receiver.)

Waves: See Surface Waves and Space Waves.

Wave Length. The shortest distance between two points in a sustained plane wave group or train such that magnitude and rate of change of magnitude of the disturbances at those points are completely identical. In general, it is twice the distance between a point of zero disturbance and the next point of zero disturbance. Wave length should always be expressed in meters.

Wave Meter. A radio frequency measuring instrument calibrated to read wave lengths.

LITERAL SYMBOLS.

1. (Symbols arranged alphabetically).

Units used should be those of PRACTICAL SYSTEM, e. g., the volt, ampere, ohm, henry, farad, etc., and their multiples and submultiples. The inductances and capacities in radio frequency circuits should be normally expressed in microhenrys and microfarads respectively.

a	Damping Factor (that is, R/2L) (Time reciprocal)
A	Attenuation Coefficient (Distance Reciprocal)
A_f	Audibility Factor
b	Linear Decrement (Numeric)
B	Magnetic Induction
c	Capacity (at audio frequencies) (Farads)
C	Capacity (at radio frequencies) (Farads)
C_d	Distributed Capacity (Farads)
d	Logarithmic Decrement (that is, RT/2L) (Numeric)
e	Instantaneous Value of Voltage. May also be used for E. M. F. of individual cells of a battery or accumulator, etc.) (Volts)
E	R. M. S. Value of Voltage (Volts)
E_m	Maximum Value of Voltage, (Amplitude) (Volts)
E_R	Resonance Voltage (Volts)
EFF	Efficiency (Numeric)
h	Effective Height of Antenna (Meters)
ht	Actual height (e. g. of antenna) (Meters)
H	Magnetic Force (Gilberts per cm.)
i	Instantaneous Value of Current (Amperes)
I	R. M. S. Value of Current (Amperes)
I_m	Maximum Value of Current (Amplitude) (Amperes)
I_R	Resonance Current (Amperes)
I_r	Received Current (Amperes)
I_s	Transmitting (Atenna) Current
j	$\sqrt{-1}$
k	Coefficient of Inductive Coupling **(that is,** $\frac{M}{\sqrt{L_1 L_2}}$) (Numeric)
K	Dielectric Constant (Specific Inductive Capacity)
k_c	Coefficient of Capacity Coupling (Numeric)
l	Inductance (at audio frequencies) (Henrys)
L	Inductance (at radio frequencies) (Henrys)
L_d	Distributed Inductance (Henrys)

M	Coefficient of Mutual Inductance (Henrys)
n	Frequency, in complete cycles
N	Group Frequency (e. g., sparks per second)
p	Instantaneous Value of Power (Watts)
P	Mean Value of Power (Watts)
PF	Power Factor (Numeric)
Q	Quantity of Electricity (Coulombs)
r	Resistance (at audio frequencies) (Ohms)
R	Resistance (at radio frequencies) (Ohms)
R_a	Apparent Total Antenna Resistance (Ohms)
R_f	Radiation Resistance (Ohms)
s	Distance (between stations, e. g.) (Km.)
t	Time (as a variable) (Seconds)
T	Period of one Cycle or Complete Oscillation (Seconds)
W	Energy (Joules, or Watt-hours)
W_e	Electrical Energy (Joules, or Watt-hours)
W_m	Magnetic Energy (Joules, or Watt-hours)
X	Reactance. (When X is positive, it denotes preponderance of inductive reactance, and when X is negative it denotes preponderance of capacity reactance.) Reactance always equals $2\pi nL—(1—/2\pi nC)$
Z	Impedance (It is the square root of the sums of the squares of the resistance and the reactance of a circuit.) $R + jL\omega$ represents inductive impedance and $R - (j/C\omega)$ represents impedance containing capacity reactance component. (Ohms) $Z = \sqrt{R^2 + \left(L\omega - \frac{1}{\omega C}\right)^2}$
a	Form Factor (of antennae) (Numeric)
μ	Permeability
μa	Microampere
μv	Microvolt
μw	Microwatt
μh	Microhenry
μf	Microfarad

(In general, the prefix μ shall indicate "Micro," and the letter "m," used as a prefix, shall indicate "milli.")

λ	Wave Length (Meters)
ϕ	Magnetic Flux (Maxwells)
ω	Angular Velocity, that is 2π times the frequency (Radians per second.)

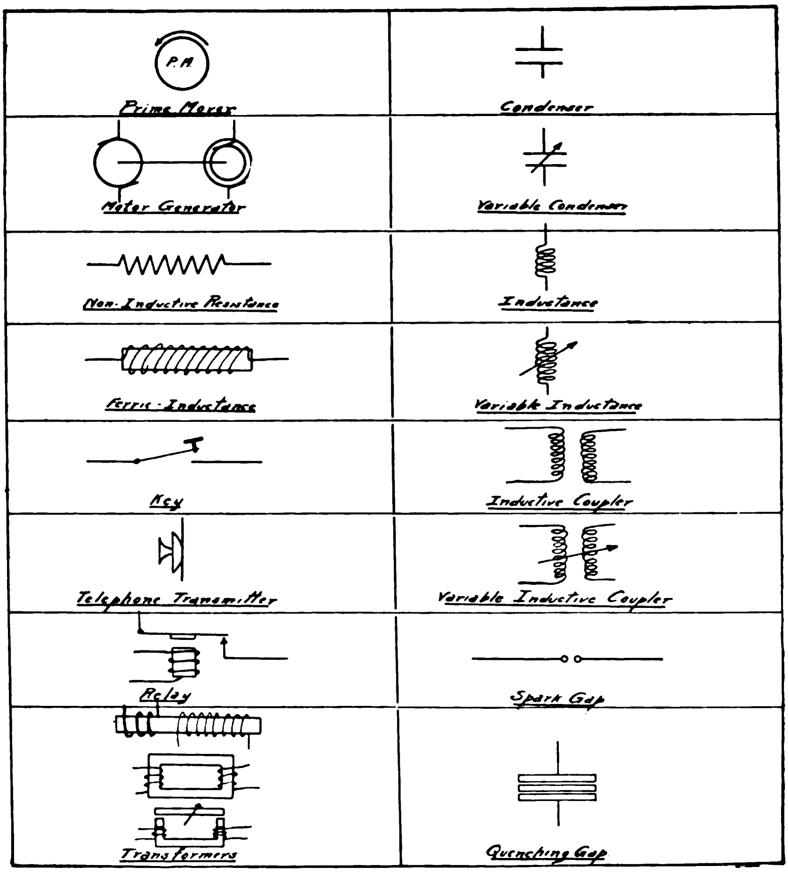
LITERAL SYMBOLS.

2. (*Arranged alphabetically according to the terms symbolized*).

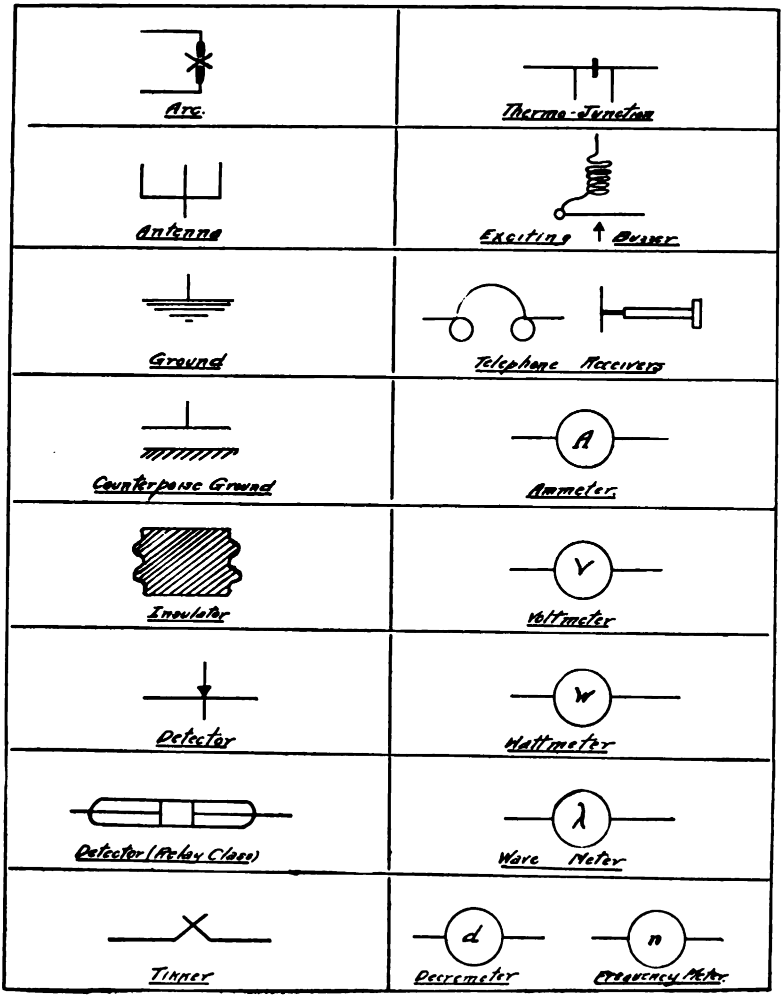
ht	Actual Height (e. g. of antenna) (Meters)
ω	Angular Velocity, that is 2π times the frequency. (Radians per second.)
R_a	Apparent Total Antenna Resistance (Ohms)
A	Attenuation Coefficient (Distance reciprocal)
A_f	Audibility Factor
c	Capacity (at audio frequencies) (Farads)
C	Capacity (at radio frequencies) (Farads)
k_c	Coefficient of Capacity Coupling (Numeric)
k	Coefficient of Inductive Coupling (that is, $\left(\frac{M}{\sqrt{L_1 L_2}}\right)$ (Numeric)
M	Coefficient of Mutual Inductance (Henrys)
a	Damping Factor, (that is, R/2L) (Time reciprocal)
K	Dielectric Constant (Specific Inductive Capacity)
s	Distance (between stations, e. g.) (Km.)
C_d	Distributed Capacity (Farads)
L_d	Distributed Inductance (Inductance)
h	Effective Heights of Antenna (Meters)
EFF	Efficiency (Numeric)
W_e	Electrical Energy (Joules, or Watt-hours)
W	Energy (Joules, or Watt-hours)
δ	Form Factor (of antennae) (Numeric)
n	Frequency, in complete cycles
N	Group Frequency (e. g., sparks per second)
Z	Impedance (It is the square root of the sums of the squares of the resistance and the reactance of a circuit). $R + jL\omega$ represents inductive impedance and $R - (j/C\omega)$ represents impedance containing a capacity reactance component. (Ohms) $Z = \sqrt{R^2 + \left(L\omega - \frac{1}{\omega C}\right)^2}$
i	Instantaneous Value of Current (Amperes)
p	Instantaneous Value of Power (Watts)
e	Instantaneous Value of Voltage (May also be used for E. M. F. of individual cells of a battery or accumulator, etc.) (Volts)

l	Inductance (at audio frequencies) (Henrys)
L	Inductance (at radio frequencies)
b	Linear Decrement (Numeric)
d	Logarithmic Decrement (that is RT/2L) (Numeric)
W_m	Magnetic Energy (Joules, or Watt-hours)
ϕ	Magnetic Flux (Maxwells)
H	Magnetic Force (Gilberts per cm.)
B	Magnetic Induction
I_m	Maximum Value of Current (Amplitude), (Amperes)
E_m	Maximum Value of Voltage (Amplitude), (Volts)
P	Mean Value of Power (Watts)
μa	Microampere
μf	Microfarad
μh	Microhenry
μv	Microvolt
μw	Microwatt
T	Period of one Cycle or Complete Oscillation (Seconds)
μ	Permeability
PF	Power Factor (Numeric)
Q	Quantity of Electricity (Coulombs)
R_f	Radiation Factor (Ohms)
X	Reactance. (When X is positive, it denotes preponderance of inductive reactance, and when X is negative it denotes preponderance of capacity reactance.) Reactance always equals $2\pi nL-(1/2\pi nC)$
r	Resistance (at audio frequencies) (Ohms)
R	Resistance (at radio frequencies) (Ohms)
I_r	Received Current (Amperes)
I_R	Resonance Current (Amperes)
E_R	Resonance Voltage (Volts)
I	R. M. S. Value of Current (Amperes)
E	R. M. S. Value of Voltage (Volts)
j	Square root of minus one ($\sqrt{-1}$)
t	Time (as a variable) (Seconds)
I_s	Transmitting (Antenna) Current
λ	Wave Length (Meters)

GRAPHICAL SYMBOLS.



GRAPHICAL SYMBOLS.



TESTS AND RATING.

The Committee on Standardization has further planned a series of preliminary recommendations relating to testing and rating apparatus for radio transmission. This work is in progress, and will be further reported in the future. The two following rules are, however, of sufficient importance to warrant submitting them to the radio engineering profession for immediate criticism and suggestion.

1. All radio transmitting sets shall be rated in actual power output measured in the antenna.

The Committee is aware of some of the theoretical and practical difficulties involved in making a measurement of the actual power output in an antenna, but is convinced that they are far from sufficient to justify discarding this unquestionably just method of rating. The group or audio frequency of the note of the station should be stated as well, (except for sustained wave sets, where that characteristic should be mentioned).

2. The over-all efficiency of a radio transmitting station shall be the quotient of the actual power* output measured in the antenna to the power* input supplied to the first piece of electrical machinery which is definitely a part of the radio equipment.

* Or the corresponding total energy, as explained below.

Examples of the application of this rule are the following: (a) A ship station. Direct current is supplied from the ship's mains to a motor generator set, which furnishes alternating current to the high tension transformer of the radio set. The ratio of power in the antenna to power supplied to the motor of the motor generator set and to the auxiliary radio equipment (e. g., blower motors, rotary gap motors) is the over-all efficiency.

(b) An auxiliary ship station. Storage batteries are charged from the ship's mains, and operate a motor generator set or an induction coil. The over-all efficiciency is the ratio of the kilowatt-hours supplied to the storage battery for a full charge to the kilowatt- hours delivered by the antenna circuit during the complete time of discharge. The energy ratio, rather than the power ratio, is here required, because of the method of storing energy in such batteries. It may be conveniently measured by the ratio of (kilowatt-hours on discharge of the storage battery to kilowatt-hours on charge) multiplied by the ratio of (power delivered in the antenna to power supplied by the storage battery to the radio equipment.) This method is closely approximate.

(c) A land station. High voltage alternating current (2,200 volts, for example) is supplied to the station from local power mains. This is stepped down to operate a motor generator set which supplies current of the definite type desired for the station. The over-all efficiency is the ratio of the power output of the antenna to the power supplied by the step-down transformer. If the step down transformer feeds other electrical machinery or apparatus not a part of the radio equipment, (e. g., lamps), the power supplied to such apparatus shall be subtracted from the total power supplied by the step-down transformer when calculating the over-all efficiency. If the motor generator in question is used to charge storage batteries which operate the station, an energy ratio, somewhat as in case (b) above, must be taken instead of the power ratio.

(d) A land station. A large steam engine operates directly or indirectly an audio or radio frequency alternator which supplies current to the radio station exclusively. The over-all efficiency is the ratio of the power output in the antenna to the brake kilowatts of the engine driving the alternator.

(e) A land station. A steam or gasoline engine drives a high voltage direct current generator which feeds directly or indirectly arcs or special gap discharges in the station. The ratio of the antenna power to the brake kilowatts of the engine is the over-all efficiency, (under similar conditions to those of (c) above.)

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NAME	DATE	NAME	DATE
		H. H. Henline	5-5-23
Bindery Sample	Jan 10-16	W. T. Sumerlin	JAN 18 1939
F. P. Andrews	JAN 2 1917	Inter-Library Loan	
"	JAN 10 1917	Univ of Calif.	1-5-45
			FEB 16 '45
Geo Royden	MAY 8 - 1917		
Geo Royden.	SEP 28 1917	C. F. Elwell	
Geo Royden	JAN 22 1918	C. F. Elwell	OCT 1 '54
E. E. Lilby JCC	3/6/18	~~C. F. Elwell~~	JUN 12 '58
Eske Beale	JUN 15 1921	~~FIS/AD (SYLVANIA)~~	~~1-25-80~~
Marker	6-7-21	Repair	JUN 1 '80